Senior Thesis

An Investigation of the Hydrogeologic Connections Among the Scioto River, the Glacial-Outwash Aquifer, and the Carbonate Aquifer at the South Well Field, Southern Franklin County, Ohio.

by

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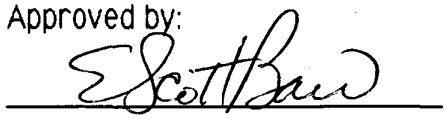
Approved by:



Dr. E. Scott Bair

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ABSTRACT

This study was conducted to determine the relative contributions from the glacial-outwash aquifer, upward leakage from the carbonate aquifer, and induced stream infiltration from the Scioto River to the three radial-collector wells located along the east floodplain of the Scioto River in Southern Franklin County, Ohio. These wells are used for municipal purposes by the county and by the City of Columbus and provide about 15 percent of the local water supply.

The study is based on water-quality analyses of samples of the various source waters. Potential mixing of the source waters in the collector wells was analyzed using the results of ten samples from the Scioto River, three samples from the collector wells, five samples from the glacial-outwash aquifer, and seven samples from the carbonate aquifer. Piper diagrams, ratio studies and mixing diagrams were used to determine if mixing is occurring. For ions which indicated mixing calculations of the relative contributions were performed using the mixing equation.

Results indicate that induced stream infiltration from the Scioto River accounts for about 26 percent of the water produced by the collector wells. No contribution from the carbonate aquifer was indicated by the mixing evaluations.

Variations in ion concentrations in the Scioto River with changes in water temperature and river discharge also were examined. Graphs were constructed of ion concentration versus river discharge and versus river water temperature. These studies show that ion concentrations tend to increase as temperature decreases, and to increase as river discharge increases. These trends in water quality in the river should be reflected in the water produced by the collector wells due to induced stream infiltration.

INTRODUCTION

In 1978 the City of Columbus, Ohio, began construction of four radial-collector wells in southern Franklin County. Three of these wells are located along the floodplain of the Scioto River and one well is located along the floodplain of Big Walnut Creek. These wells are completed in a permeable, glacial-outwash, sand and gravel. The collector wells are used for municipal purposes and supply about 15 percent of the City's water. The wells normally produce about 8.2 million gallons per day (Mgd), but are capable of producing about 25 Mgd.

The wells were designed to make use of induced infiltration from the Scioto River and Big Walnut Creek. Initial studies performed by Stilson and Associates (1976) predicted that 80 percent of the water produced by the wells would be induced infiltration from the two streams. This would mean that relatively little water would be removed from storage in the glacial-outwash aquifer. If, however, the lower estimates of induced stream infiltration calculated by more recent studies (Table 1) are correct, then a significantly greater amount of water must be removed from aquifer storage, especially during times of peak demand. This would cause the cone of depression created by the pumping of the wells to expand, thereby increasing the capture zone of the wells. If the capture zone of the wells were extended far enough it might then incorporate State Routes 23 and 104 which run north and south to the east and west of the study area (Fig. 1). These are potential sources of contaminant spills, and buried gas tanks at service stations along Route 23 might also leak into the flow system.

Potential sources of water to the wells are induced infiltration from the Scioto River and Big Walnut Creek, water from storage in the glacial-outwash aquifer, and upward leakage from the carbonate bedrock aquifer into the overlying glacial-outwash aquifer.

Table 1

Estimates of the Percentage of Pumpage Derived from the Scioto River

Study	Year	Percentage	Method
Stilson	1976	81	Hydrologic Budget*
Stowe	1979	74	Hydrologic Budget*
Weiss and Razem	1980	70	Computer Model
Razem	1983	32	Computer Model
de Roche and Razem	1984	20	Geochemical Model
Eberts	1987	13	Computer Model

* Based in part on pumping test data

(From Moreno, 1988)

PURPOSE AND SCOPE OF STUDY

In light of the residential, commercial, and industrial growth in the Columbus area, it is becoming increasingly necessary for city and county officials to be aware of available water resources. This report presents the results of a study to determine the relative contributions from the various potential sources of water to the collector wells. These sources include the glacial-outwash aquifer, potential upward leakage from the carbonate bedrock aquifer, and induced infiltration from the Scioto River and Big Walnut Creek.

The mixing of these waters is analyzed on the basis of major-ion chemistry. Fluctuations in the concentrations of dissolved calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate due to changes in river temperature and river discharge also are examined. Due to the limitations of the available data, only the three collector wells along the Scioto River are considered.

HYDROGEOLOGIC SETTING OF THE STUDY AREA

The study area is located in the Scioto River basin in southern Franklin County, Ohio. Big Walnut Creek is a tributary to the Scioto River and enters it in Pickaway County, about one-half mile south of the Franklin County line (Fig. 1). Both streams generally trend north and south through the study area. River discharge is highly variable. During the 1987 water year (October 1986 through September 1987) discharge ranged from 149 cubic feet per second (cfs) to 17,100 cfs, with an average discharge of 1852 cfs (USGS, 1987).

Deposits of alluvial silt, clay, and sand (Schmidt and Goldthwait, 1958) cover the Scioto River floodplain in a layer 10 to 15 feet thick (Weiss and Razem, 1980) (Fig. 2). Extensive agricultural use is made of the floodplain area.

Below the alluvium are extensive Pleistocene glacial deposits (Fig. 2). According to Goldthwait (1958) the tills that are present are the product of two glacial advances and subsequent retreats during the Wisconsinan glacial event. The first of these advances occurred about 50,000 years ago and the second advance about 22,000 years ago (Schmidt and Goldthwait, 1958). These deposits are over 115-feet thick within the study area (Stilson and Associates,1976). The deposits are very heterogenous in both mineralogic and hydrologic characteristics. Igneous, metamorphic, and sedimentary rocks are found within the till (de Roche and Razem, 1984) and grain sizes vary from clay-sized to boulders up to 5 feet in diameter (Goldthwait, 1958).

These materials generally are very permeable and are the major source of ground water in the area. In the study area, the glacial-outwash aquifer has a saturated thickness of 55 to 85 feet (Norris, 1986). Hydraulic conductivity is variable and ranges from 200 to 330 feet per day (ft/d) in the Scioto River valley (Eberts, 1987).

The glacial-outwash aquifer is underlain by the Delaware and Columbus Limestones (Fig. 3). These are Devonian in age and, although not as permeable as the glacial-outwash aquifer, do conduct significant quantities of water and commonly are used as the source of domestic and industrial water supplies. These

units also may supply water to the glacial-outwash aquifer from upward leakage under favorable vertical head gradients.

In the area near Big Walnut Creek, the Olentangy Shale is present between the glacial-outwash aquifer and the carbonate aquifer and is located about 125 feet below land surface (Stilson and Associates, 1977) (Fig. 3). The presence of the relatively impermeable shale should inhibit upward leakage into the glacial-outwash aquifer. It also should modify the ground-water chemistry in this area, relative to the area near the Scioto River.

In terms of the total dissolved solid (TDS) content of these waters, the glacial-outwash aquifer has the best water quality, followed by the Scioto River and then the carbonate aquifer (Table 2). The average TDS content of the glacial-outwash aquifer is about 470 milligrams per liter (mg/L), whereas the average TDS content of the carbonate aquifer is about 620mg/L, and the average TDS content of the Scioto River is about 490 mg/L. The U. S. Environmental Protection Agency secondary water-quality standard for TDS is 500 mg/L. The TDS content of the carbonate aquifer is higher due to its longer residence time in the ground-water flow system. Thus, it has had a longer time to accumulate dissolved ions.

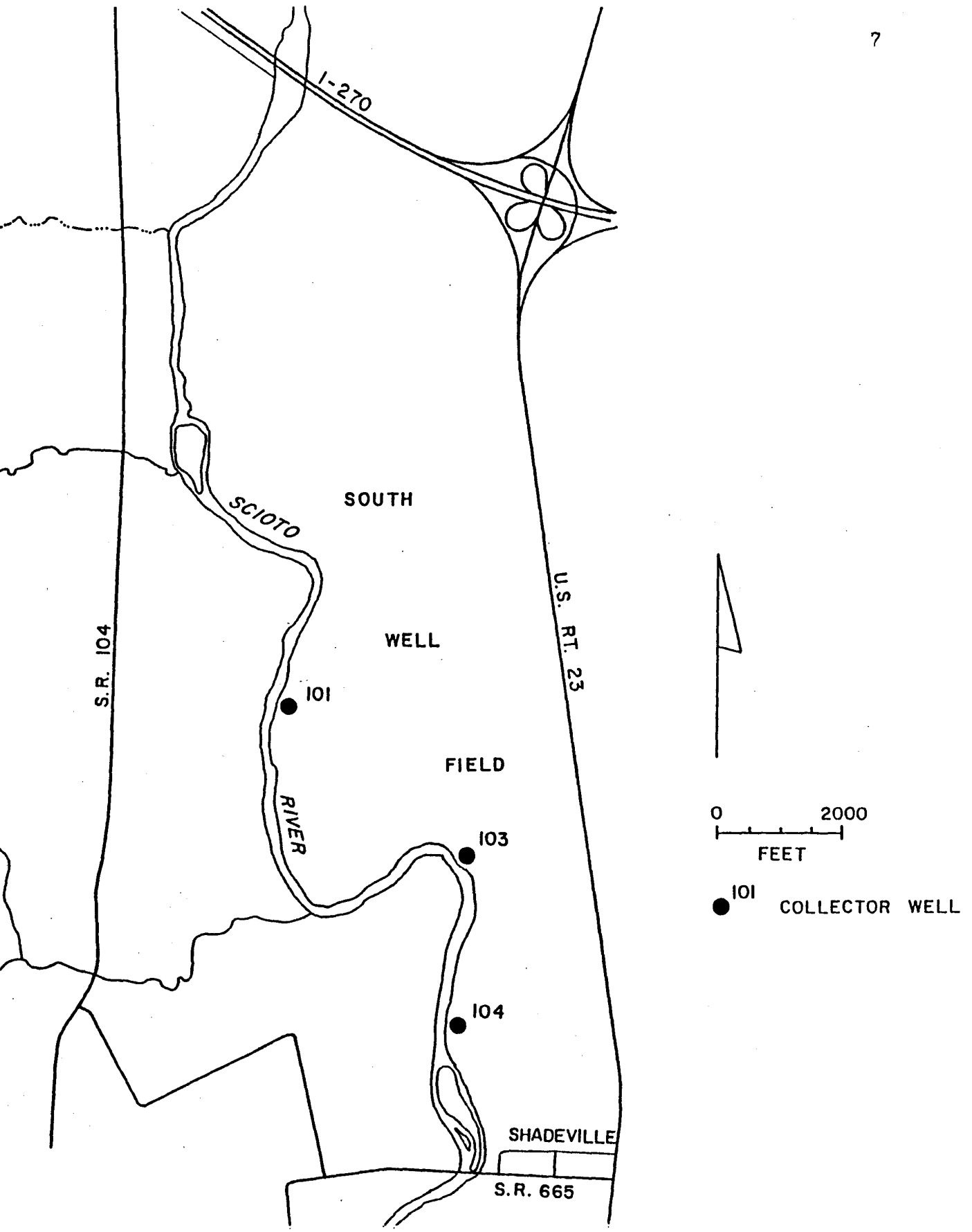
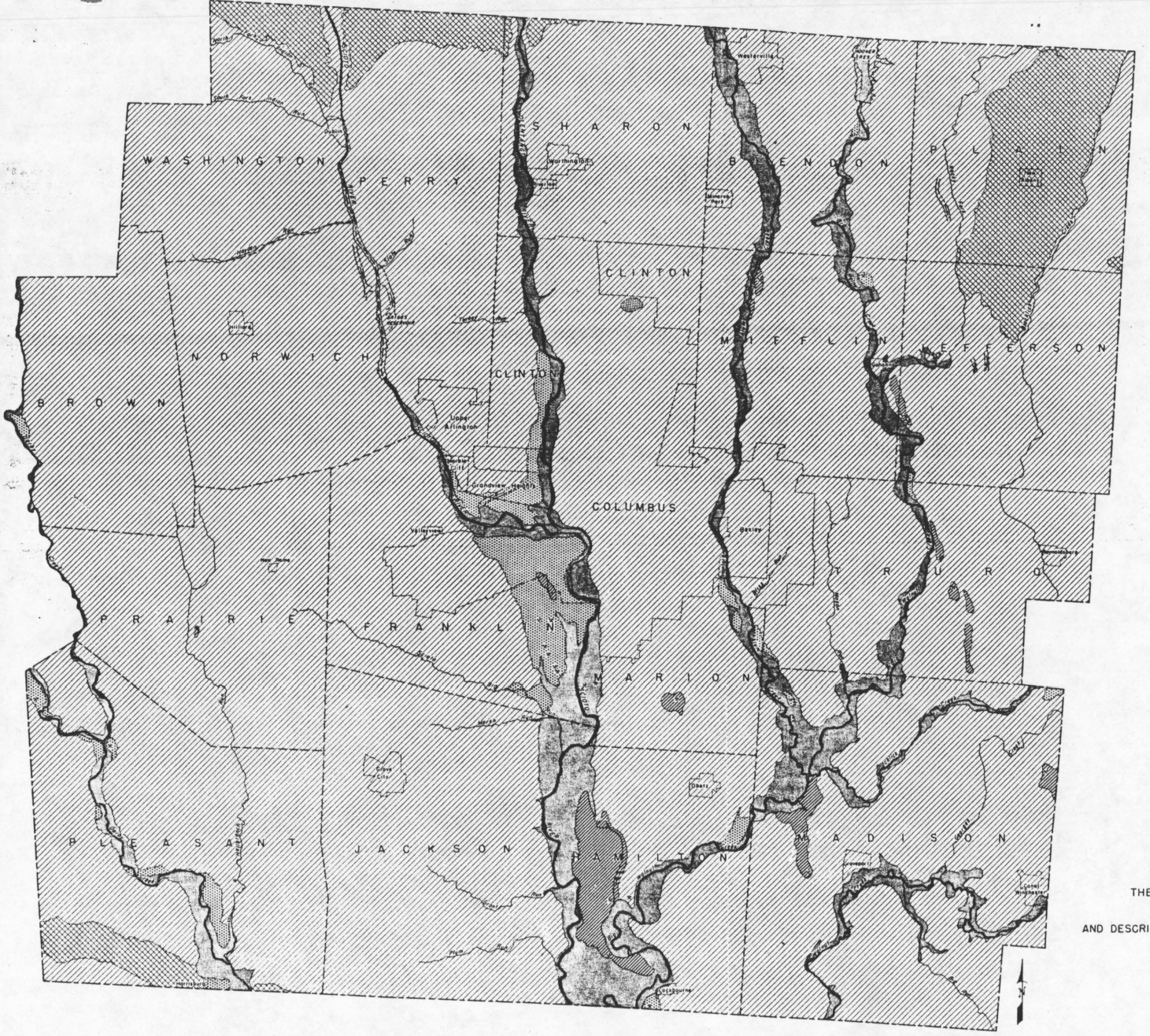


Fig.1 Map of Study Area
(From Moreno, 1988)



EXPLANATION

RECENT

ALLUVIAL DEPOSITS
Silt and gravel deposited by the present streams on their flood plains. Because these deposits are thin and generally impermeable, they are not a source of ground water. Wells that penetrate these deposits may encounter valley-train deposits, and yield large ground-water supplies.

PLEISTOCENE (WISCONSIN STAGE)

VALLEY-TRAIN DEPOSITS
Outwash deposits of sand and gravel deposited in the valleys by flooding meltwater from the glacier. These deposits occur above present drainage as gravel terraces and generally do not receive infiltration from major streams. These deposits are very permeable and increase the recharge potential for the underlying formations, which usually consist of valley-train deposits below drainage.

KAMES AND ESKERS
Sand and gravel deposited as hills and ridges. Some of these are covered with thin till or contain till masses. Quantity of water obtainable depends upon the thickness of the material and amount of recharge.

END MORAINE
Generally till, in places stony or sandy, with interbedded sand and gravel lenses. Deposited as hills and ridges at the edge of the glacier. Small farm and domestic water supplies are generally developed from wells in the lenses of sand and gravel.

GROUND MORAINE
Till generally more than 20 feet thick, although bedrock may be exposed in a few places. Meager water supplies in the till, but adequate supplies for farm and domestic use are sometimes developed in the thin lenses of sand and gravel interbedded in the till.

LAKE BEDS
Clay and silt which settled in small lakes near the melting ice edge. These deposits range from 10 to 20 feet thick and are not a source of ground water.

Drainage Channels

Gravel Pit

MAP OF
THE ALLUVIAL AND GLACIAL DEPOSITS OF
FRANKLIN COUNTY, OHIO
AND DESCRIPTION OF THEIR WATER-BEARING PROPERTIES

GEOLOGY BY RICHARD P. GOLDTHWAIT

SCALE IN MILES
0 1 2 3 4

Figure 2 Map of Surface Geology (From Schmidt and Goldthwait, 1958)

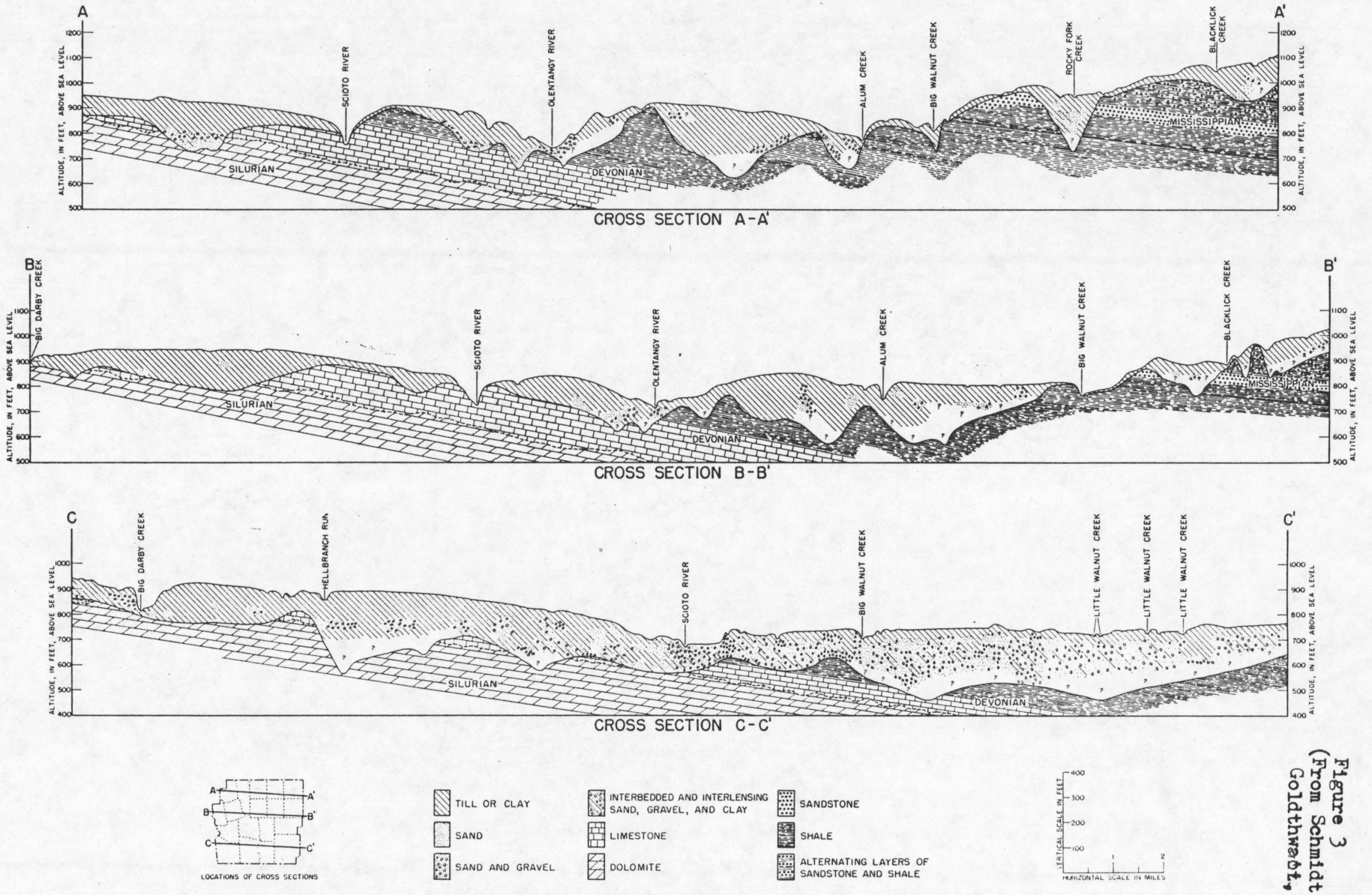


Figure 3 (From Schmidt and Goldthwait, 1958)

Generalized cross sections showing geology of Franklin County, Ohio.

Table 2 Water Quality of the Source Waters by Total Dissolved Solid (TDS) Content

Sampling Site	Calculated TDS
Surface Water Sites in the Scioto River	
SR1	303
SR2	553
SR3	546
SR4	533
SR5	493
SR6	511
SR7	493
SR8	481
SR9	508
SR10	499
Samples from Collector Wells	
CW101	458
CW103	472
CW104	450
Samples from the Glacial-Outwash Aquifer	
FR147	511
FR73	392
FR18	587
FR120	381
FR141	498
Samples from the Carbonate Aquifer	
FR202	598
FR202A	593
FR148	440
FR234A	454
FR246A	714
FR264A	893
FR223SA	631

HYDROGEOLOGIC SETTING OF THE COLLECTOR WELLS

All four of the radial-collector wells are completed in the glacial-outwash aquifer. Specifications of the wells are listed in Table 3. Collector wells 103 and 104 have two tiers of laterals, whereas collector wells 101 and 115 have three tiers and one tier of laterals respectively. The total length of the laterals varies from 1066 feet in collector well 115 to 1732 feet in collector well 101. Most of the laterals are 16 inches in diameter but some of the laterals in collector well 103 are 12 inches in diameter. The depth of the wells varies from 74 to 109 feet.

This type of well was constructed in an attempt to induce infiltration from the Scioto River and Big Walnut Creek into the local ground-water flow system. The wells have a large diameter central caisson from which lateral well screens extend outward in a radial pattern (Fig. 4). Some laterals extend to distances of over 300 feet. This increases the diameter of the cone of depression created during pumping and creates downward hydraulic gradients in the streambed and upward hydraulic gradients in the carbonate bedrock. Infiltration from the stream then acts as a source of recharge to the glacial-outwash aquifer, thereby increasing the sustained yield which may be obtained from the aquifer. The degree to which this occurs in the carbonate aquifer is unknown.

Table 3

Collector-Well Statistics

Well Number	101	103	104	115
Location	Scioto River	Scioto River	Scioto River	Big Walnut Creek
Depth of Well (ft)	74	109	86	68
Number of Laterals	10	16	15	7
Levels of Laterals	3	2	2	1
Total Length of Laterals (ft)	1732	1233	1370	1066
Diameter of Laterals (in)	16	12/16	16	16
Production Capacity (Mgd)	13.4	14.4	7.2	7.6

(From Stilson, 1976)

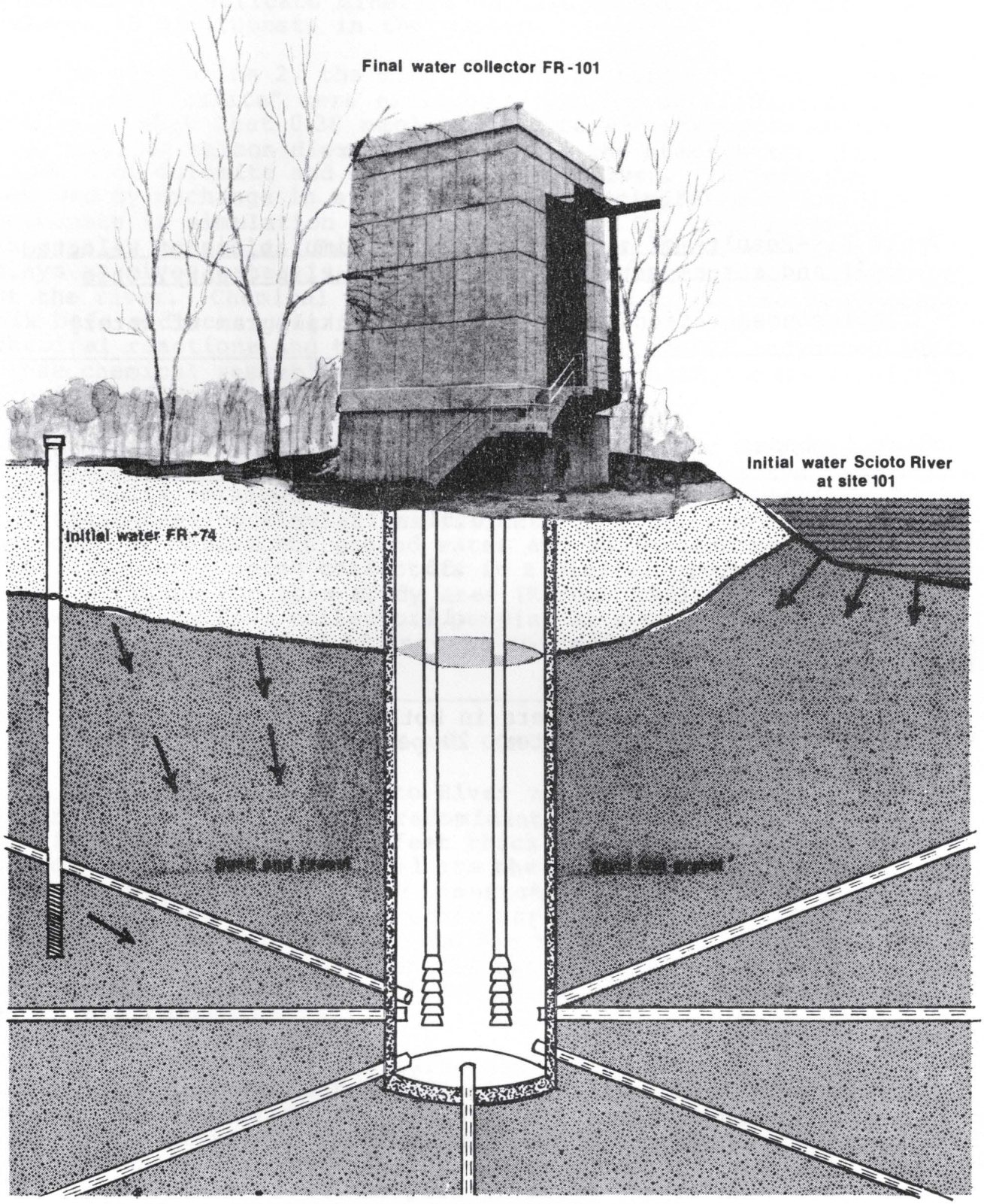


Figure 4 .--Conceptual diagram showing radial collector and mixing of ground water and surface water.

(From de Roche and Razem, 1984)

SOURCES AND TYPES OF WATER QUALITY AND HYDROLOGIC DATA

Data used in this study are taken from various U. S. Geologic Survey reports (de Roche and Razem, 1984; de Roche, 1985; U. S. Geological Survey, 1987). The data used to evaluate potential mixing in the collector wells are based on analyses of samples obtained from the collector wells, wells in the glacial-outwash aquifer, wells in the carbonate aquifer, and samples from the Scioto River. Major ionic constituents are used to determine the potential mixing of these waters in the collector wells. Ionic concentrations are reported in milligrams per liter (mg/L), which are equal to parts per million (ppm), in dilute waters. These concentrations have then been converted to equivalent parts per million (epm) concentrations to make comparisons on a charge balance basis. This was done using the following formula:

epm= ppm/[gram formula weight of the ion/valence of the ion]

Table 4 lists the various conversion factors needed in these calculations.

Table 4

List of Conversion Factors: Parts per Million (ppm) to Equivalent Parts per Million (epm)

Solute	Gram Formula Weight	Gram Equivalent Weight (gew)	ppm to epm (ppm/gew)
Ca^{2+}	40.08	20.04	0.04990
Mg^{2+}	24.31	12.16	0.08224
Na^{+}	22.99	22.99	0.04350
K^{+}	39.10	39.10	0.02558
HCO^{3-}	61.02	61.02	0.01639
$SO4^{2-}$	96.06	48.03	0.02082
Cl^{-}	35.45	35.45	0.02820

FACTORS AFFECTING POTENTIAL MIXING

Factors controlling the potential contribution from the three sources to the water in the collector wells include pumping rates, the permeability of the streambed, the temperature of the water, the river stage, hydraulic conductivity distribution of the aquifers, and the head gradients in the aquifers.

Pumping rates are controlled by operators at the Parsons Avenue Water Treatment Plant and are varied based upon the demand for water. An increase in pumping rate will increase the amount of infiltration from the streams due to the increase in the vertical hydraulic gradient across the streambed between the water level in the streams and the hydraulic head in the glacial-outwash aquifer.

Vertical hydraulic gradients across the interface between the glacial-outwash aquifer and the carbonate aquifer also will increase with an increase in pumping rate. Thus, increasing the upward leakage of water from the carbonate aquifer.

Although an increase in pumping rate may increase the amount of water derived from the carbonate aquifer and the streams, the relative percentage of water coming from these sources to the collector wells may, or may not, remain the same.

The factor which most inhibits downward movement of water from the streams, despite a favorable downward hydraulic gradient, is streambed permeability. This factor is highly variable within the study area (Moreno, 1988) (Table 5). Although the streams are underlain by the glacial-outwash aquifer, which is composed of highly permeable sand and gravel, some parts of the streambed are composed of relatively impermeable silt and clay. Silt and clay fall from suspension in the water column in lower energy areas of the stream. These areas are termed pools. Pools are depressions in the topography of the streambed which, under normal to low river stages , experience very velocity water currents. Pools make up about 18 percent of the streambed, the remainder being runs and riffles where the streambed is composed of more permeable, poorly sorted, sands and gravels (Moreno, 1988).

Downward infiltration also is affected by the temperature of the river water. Viscosity is the resistance of a fluid to flow, and, in the case of water, is inversely proportional to the temperature of the water. Consequently, water in the Scioto River and Big Walnut Creek should infiltrate downward more readily at higher water temperatures during the summer months than at low water temperatures during the winter months.

River stage has two effects on the downward infiltration of stream water. Both of these effects relate to the cross-sectional area, or geometry, of the streambed. For the purposes of this discussion only a simple analysis is necessary. An increase in stream width during higher river stages means that more of the streambed is covered by water. Because streambed permeability is highly variable, this could cause significant changes in the amount of water moving downward under favorable hydraulic gradients. Increased river stage also would increase the driving head of the water at any point on the streambed. This would increse the downward force on water particles and would enhance their downward movement. Likewise, a drop in river stage would lessen the driving head and the downward force would be less. The amount of water that can move downward into the glacial-outwash aquifer from the streams is controlled by the hydraulic conductivity of the streambed and the vertical hydraulic gradient across the streambed. The temperature of the surface water also affects the hydraulic conductivity of the streambed.

The hydraulic conductivity of the carbonate aquifer is lower than it is in the glacial-outwash aquifer. This means that as water in the glacial-outwash aquifer moves toward the collector wells some of it is replaced by upward leakage from the carbonate aquifer under favorable vertical hydraulic gradients. The rest of the water must come from storage in the glacial-outwash aquifer.

Because the Scioto River is the regional discharge area for the carbonate aquifer, natural upward hydraulic gradients exist below the Scioto River within the carbonate aquifer. These upward hydraulic gradients are enhanced by pumping

the collector wells. Thus, upward leakage from the carbonate aquifer will be greatest below the collector wells, and particularly below the lateral well screens which extend below the river. The natural upward leakage is, in part, controlled by the ground-water level, or driving head, in the aquifer at its recharge area located to the west of the study area.

Table 5
Vertical Hydraulic Conductivity (Kv) Values for the Streambed of the Scioto River

Station	River Setting	Unadjusted Kv (feet/day)	Temperature (^{o}C)	Kv Adjusted to 12 ^{o}C (feet/day)
104A	Run	0.08	22.5	0.06
104B	Run	0.08	22.5	0.06
104C	Run	----	22.5	----
270A	Run	0.71	23.0	0.54
270B	Run	0.15	23.0	0.11
270C	Run	0.11	23.0	0.08
101A	Run	0.64	22.0	0.50
101B	Run	0.09	22.0	0.07
101C	Run	0.78	22.0	0.61
RF101A	Riffle	3.02	22.0	2.36
RF101B	Riffle	0.26	22.0	0.20
RF101C	Riffle	0.05	22.0	0.04
RF101D	Pool	0.44	22.0	0.34
102A	Run	4.35	17.0	3.82
102B	Run	----	17.0	----
102C	Run	1.08	17.0	0.95
103A	Riffle	0.04	12.5	0.04
103B	Riffle	----	12.5	----
103C	Riffle	0.17	12.5	0.17
100A	Run	----	14.5	----
100B	Run	0.33	14.5	0.31
100C	Run	0.19	14.5	0.18
665A	Run	1.56	11.5	1.59
665B	Run	3.81	11.5	3.87
665C	Run	2.99	11.5	3.04
Mean		1.00	18.3	0.90

---- Unable to measure Kv because of inability to seal seepage meter or locate potentiometric surface with peizometer.

(From Moreno, 1988)

METHODS OF ANALYSIS

Differentiation of Water Types

The first step in analyzing the data was to determine that the water from each of the three potential sources and from the collector wells could be differentiated on the basis of their major-ion chemistry.

The chemistry of ground water will reflect the rock type through which it has moved. Dissolution of sedimentary rocks and minerals such as limestone, dolomite, halite, sylvite, anhydrite, and gypsum causes concentrations of ions in the water, which include calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate. Because the principal rock types in the aquifers are different, these ions should show different concentrations in the carbonate aquifer than they do in the glacial-outwash aquifer. Concentrations of these ions range from about 1 part per million (ppm) to over 650 ppm.

The chemistry of the water in the Scioto River is controlled primarily by the discharge from the Jackson Pike Sewage Treatment Plant, especially at times of low river discharge.

Because the collector wells are completed in the glacial-outwash aquifer, any deviation in water chemistry in the collector wells from that in the glacial-outwash aquifer, beyond normal seasonal variations, is an indication that mixing is occurring.

Analysis of the chemical differences between sources was done by comparison of concentrations of major cations and anions, ratio studies of major ions, and through the use of Piper diagrams. Reported concentrations (Table 6) measured in milligrams per liter (mg/L) were initially converted to equivalents per million (epm) using the conversion factors listed in Table 4. Epm concentrations then were analyzed to determine if waters from the different potential sources had different chemical characteristics. This was done by examining individual ion concentrations and the ratios of different ion pairs using a Piper plotting program (Quick, 1986). The Piper plotting program also was used to show that the waters from the various sources had different chemical characteristics. Piper diagrams

Table 6
Data used to analze mixing
reported in milligrams per liter (mg/L)

NAME	CA	MG	NA	K	CL	SO4	CO3	HCO3
SR1	59.0	19.0	20.0	4.6	34.0	83.0	0.0	170.0
SR2	93.0	23.0	57.0	9.2	93.0	190.0	0.0	179.0
SR3	92.0	23.0	56.0	9.1	92.0	180.0	0.0	190.0
SR4	92.0	23.0	56.0	9.2	92.0	170.0	0.0	185.0
SR5	80.0	24.0	47.0	7.9	63.0	180.0	0.0	184.0
SR6	80.0	24.0	46.0	7.9	62.0	200.0	0.0	184.0
SR7	81.0	25.0	48.0	7.8	62.0	180.0	0.0	181.0
SR8	81.0	24.0	48.0	8.2	61.0	170.0	0.0	181.0
SR9	87.0	25.0	46.0	8.2	64.0	190.0	0.0	178.0
SR10	82.0	24.0	47.0	7.5	62.0	190.0	0.0	176.0
CW104	110.0	33.0	19.0	2.1	35.0	100.0	0.0	323.0
CW103	110.0	33.0	18.0	2.7	32.0	120.0	0.0	317.0
CW101	100.0	31.0	22.0	3.0	36.0	110.0	0.0	301.0
FR147	120.0	40.0	14.0	1.8	29.0	120.0	0.0	378.0
FR73	100.0	34.0	3.3	1.4	5.1	63.0	0.0	376.0
FR18	120.0	38.0	34.0	2.2	87.0	88.0	0.0	442.0
FR120	99.0	32.0	4.9	1.7	15.0	53.0	0.0	357.0
FR141	120.0	43.0	6.6	1.2	53.0	72.0	0.0	410.0
FR202	120.0	44.0	27.0	2.2	9.8	190.0	0.0	416.0
FR202A	100.0	43.0	28.0	2.4	2.3	220.0	0.0	400.0
FR148	24.0	54.0	46.0	5.3	60.0	230.0	0.0	43.0
FR234A	73.0	35.0	18.0	1.8	27.0	97.0	0.0	410.0
FR246A	140.0	41.0	32.0	2.6	18.0	190.0	0.0	590.0
FR264A	190.0	50.0	57.0	3.1	93.0	180.0	0.0	650.0
FR223SA	120.0	41.0	24.0	2.4	37.0	190.0	0.0	440.0

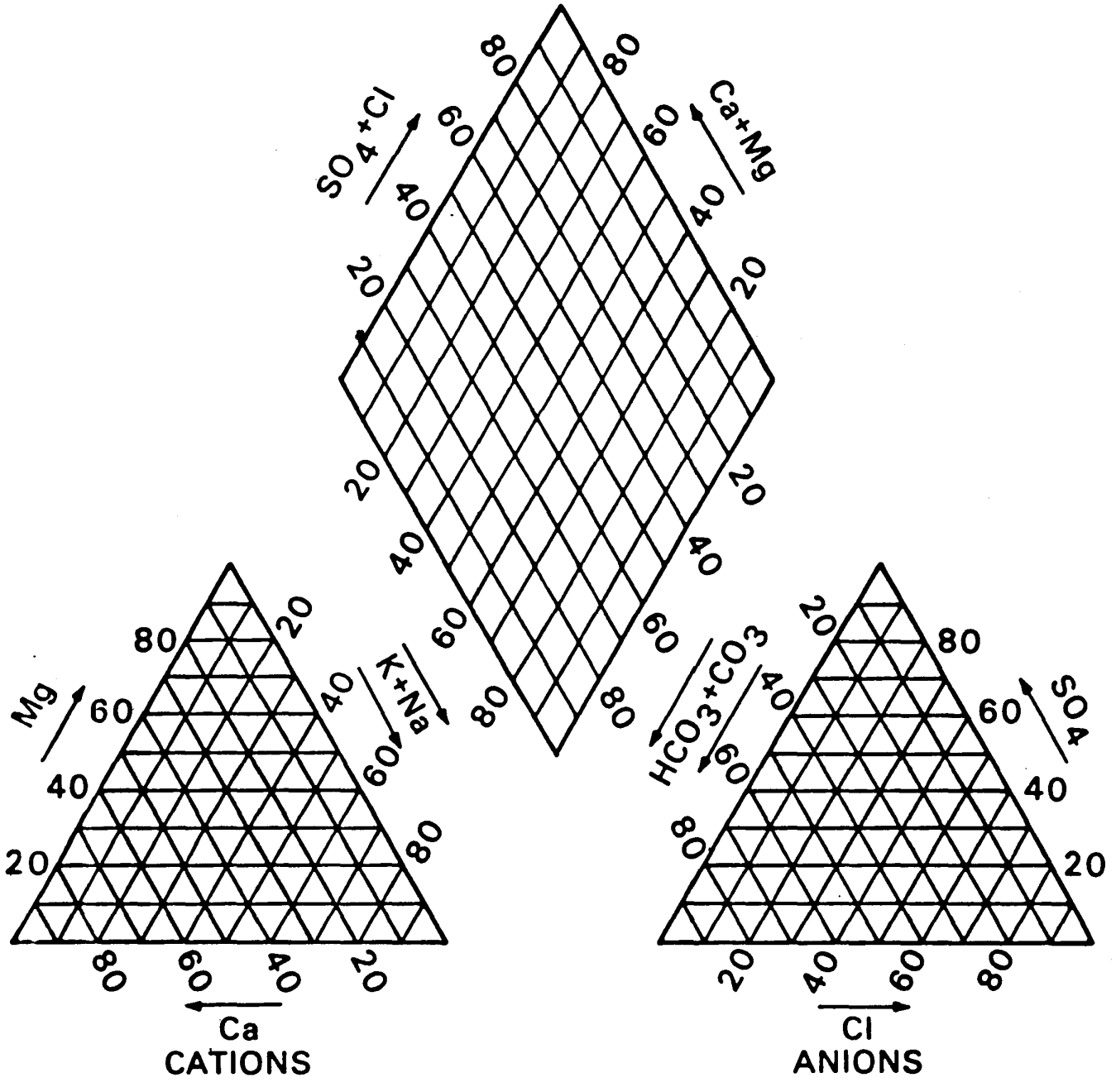
SR = Scioto River
CW = Collector Well
FR147, 18, 73, 120, 141 are wells in the glacial-outwash aquifer
The remaining wells with the FR designation are in the carbonate aquifer

are used to plot epm concentrations of major ionic constituents on a trilinear diagram (Piper, 1944) (Fig. 5). These diagrams are used to characterize water types based on major-ion chemistry and to indicate the difference between water types.

Mixing of water types also can be shown using Piper diagrams. If two end-member waters are plotted on the diamond shaped field (Fig. 5), then water from a third source which is a mixture of the other two.will plot at a point along a line connecting the end-member waters. Dilution of the water representing the mixture will cause it to plot off of the connecting line.

Figure 5

PIPER TRILINEAR DIAGRAM



Mixing Diagrams

Mixing diagrams are plots of the concentration of one ion versus the concentration of another ion. When dealing with waters from different sources that show a chemical differentiation in the ions being examined, points from each water type will plot in distinctively different fields (Fig. 6).

In this study, points representing water samples from the collector wells, the Scioto River, the glacial-outwash aquifer, and the carbonate aquifer were plotted for each combination of major ions. Points representing the average ionic concentration from each source also were plotted. A mixing triangle then was constructed. This was done by beginning a line at the point representing water in the glacial-outwash aquifer. This is the water which must be a part of the water in the collector wells because the wells are completed in this aquifer. Lines then were extended from this point toward the points representing waters from the carbonate aquifer and the Scioto River. If the point representing waters from the collector wells falls along one of these lines, then mixing from that source is indicated.

The distance along this line from the point representing the water from the collector wells to the point representing waters from the glacial-outwash aquifer is proportional to the percentage of contribution from the other source. If mixing is occurring between all three sources, then all four points will plot along a straight line. Lines extended towards the origin from the points representing the end-member waters then form a mixing triangle. Points that plot within this triangle represent waters produced by mixing and dilution.

After mixing had been indicated using the mixing diagrams , the data were analzed to determine the relative contribution from each source to the water in the collector wells. This was done using the following mixing equation:

$$X_m = f_a X_a + (1 - f_a) X_b \qquad (1),$$

where: X=ion concentration (epm)

f=the fraction of component"a" which is part of the final mixture

m=the final mixture

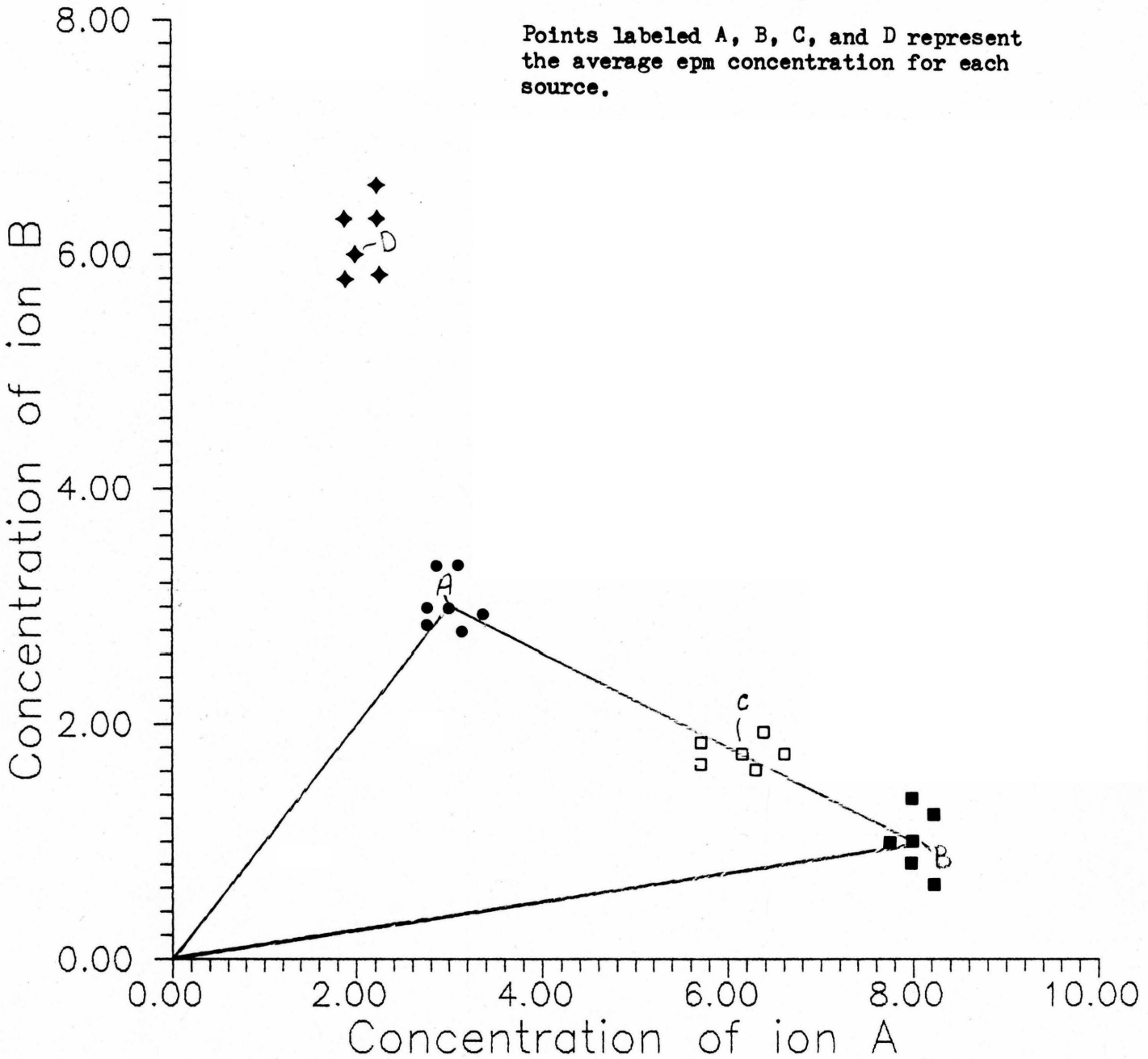
a&b=the end member waters.

Figure 6 Sample Mixing Diagram

Key

Symbol	Water Source Represented
● =	Scioto River (A)
■ =	Glacial-Outwash Aquifer (B)
□ =	Collector Wells (C)
✦ =	Carbonate Aquifer (D)

Points labeled A, B, C, and D represent the average epm concentration for each source.



Rearrangement of this formula to solve for f_a yields the following equation:

$$f_a=(X_m-X_b)/(X_a-X_b) \quad (2).$$

Analysis of all major ions for which mixing is indicated using the average ionic concentrations (Table 7) will produce a range of values for the contribution to the collector well waters from each source.

TABLE 7 Average equivalents per million (epm) concentrations used in mixing diagrams and mixing calculations

	Sources			
Ion	Scioto River [A]	Glacial Outwash Aquifer [B]	Collector Wells [c]	Carbonate Bedrock Aquifer [D]
Ca	4.13	5.58	5.32	5.47
Mg	1.92	3.08	2.66	3.62
Na	2.05	0.55	0.86	1.44
K	0.20	0.05	0.07	0.07
Cl	1.93	1.06	0.97	1.00
SO4	3.61	1.65	2.29	3.86
HCO3	2.96	6.43	5.14	6.90

Variations in Ionic Concentrations in Water From the Scioto River

Graphs of ionic concentration versus river water temperature and versus river stage from the Scioto River also were constructed. These plots were made to identify trends in changes in ionic concentrations due to changes in these two factors. If ionic concentrations do vary systematically, then changes in water quality can be anticipated during times when induced stream infiltration is higher or lower.

It was my initial intent to determine if the trends in variation of ionic concentrations from the river due to changes in water temperature and river stage were reflected in the collector-well samples and to try to analyze variations in contributions from the river with the changes in river stage and temperature. I was not able to do this because of an insufficient amount of water quality data from the collector wells at different seasons of the year.

River stage was examined as a function of river discharge from records taken at the Jackson Pike Sewage Treatment Plant.

RESULTS

The first step of examining the data to see if differentiation of water types could be achieved on the basis of major-ion chemistry was accomplished by three methods. These were analysis of the reported data, ratio studies of major ions, and analysis of Piper diagrams.

Table 8 lists values of concentrations in epm from the data used to evaluate mixing. For each ion the different types of water are characterized by different concentrations. Differences between the major ions in waters from the Scioto River, the glacial-outwash aquifer, and the collector wells show a fairly clear differentiation. Concentrations in the collector wells, however, more closely approximate those in the glacial-outwash aquifer. Differentiation between the glacial-outwash aquifer and the carbonate aquifer is less distinct. Ion concentrations in the carbonate aquifer show a greater range of values but they generally are higher than those in the glacial-outwash aquifer. The only ion which does not show good differentiation of water types is chloride. Concentrations of chloride in the glacial-outwash aquifer and in the carbonate aquifer are erratic. The reason for this behavior is not known.

Differences in ionic concentrations between water types can be enhanced by use of average ionic concentrations (Table 7) or by the use of ratio studies (Table 9). Both of these methods produce a greater differentiation of water types. The magnesium to sodium ratios in table 9 show that the ratio in the Scioto River averages about 0.9 milliequivalents per liter (meq/L) (milliequivalents per liter are equal to equivalents per million). The ratio for samples from the carbonate aquifer averages about 2.5. The average ratio in the glacial-outwash aquifer is the highest and most variable ranging from 2.11 to 19.48 meq/L with an average of about 10 meq/L. The ratio in the collector wells averages about 3 meq/L. This value is intermediate between the ratio in the Scioto River and the ratios in the glacial-outwash aquifer and the carbonate aquifer which may indicate mixing of these waters in the collector wells.

The Piper diagram (Fig. 7) shows that the prevalent chemical character of the water generally can be characterized as calcium bicarbonate, regardless of which source is examined. Water samples from each source plot within a reasonably well defined field. The density of the cluster of each set of data reflects the consistency of the data. In the cation and anion fields it can be seen that the water from the Scioto River contains higher concentrations of sulfate and chloride and lower concentrations of calcium and magnesium than the other water types. Thus, water from the Scioto River plots in a seperate field in the mixing diamond. Water from the carbonate aquifer is higher in bicarbonate and higher in magnesium than water from the glacial-outwash aquifer which is higher in calcium and lower in bicarbonate then the other water types. Water from the collector wells plots in between the water from the Scioto River and the waters from the two aquifers, but plots closer to the waters from the aquifers indicating the similarity of these water types. The arrangement of all of these water types nearly along a straight line also indicates their similarity and is potential evidence for mixing. If mixing is occurring, it would be along flow paths like those shown in figure 8.

Mixing diagrams (Appendix 1) indicate that mixing is occurring between the Scioto River and the glacial-outwash aquifer in the collector wells. This mixing is shown in figures 24-38 by the fact that the point (C), representing the collector wells,plots along, or very near, the line connecting points A and B which represent waters from the Scioto River and the glacial- outwash aquifer respectively. These results are very consistent. The only mixing diagrams which are not consistent are the ones involving the chloride ion. Chloride has erratic concentrations and does not supply adequate differentiation between water types. The reason for the inconsistent chloride concentrations is not known.

Mixing between the carbonate aquifer and the glacial-outwash aquifer in the collector wells is not indicated by these diagrams. In some instances the point D, representing waters from the carbonate aquifer, does plot in such a place that a

line could be drawn from the point representing the glacial-outwash aquifer to point D passing near point C, representing the waters from the collector wells, as seen in figure 24.

This is not a consistent feature of these diagrams, however, and the point representing waters from the carbonate aquifer usually plots in such a place that mixing from this source at the collector wells is not indicated (Fig. 26).

Table 10 shows the results of calculations of the fraction (f_a) of contribution by induced stream infiltration from the Scioto River to the water in the collector wells. This was done using equation (2). The percentage of contribution based on each ion is shown except for the chloride ion. The values range from 13 percent for the potassium ion to 38 percent for the bicarbonate ion, with an average of 26 percent for all ions. Analysis of the average values for the carbonate aquifer and the glacial-outwash aquifer by this method yields numbers less then zero and greater then one. This is additional evidence that mixing from these sources is not occurring in the collector wells.

Graphs of ion concentrations versus river stage and versus river water temperature were constructed using samples reported by the U. S. Geological Survey in 1979, 1980, and 1987 (Table 11).

Definite trends in ion concentration are indicated by these graphs (Fig. 9-15). These graphs show, with respect to all of the major ions, that ion concentration tends to increase as water temperature decreases. Figures 16 through 23 show the trend in ion concentration with variation in river stage. These tend to increase with increasing river stage. This is probably due to surface-water runoff from adjacent agricultural areas. Only the plot of potassium versus river stage (Fig. 22) does not support this conclusion.This is due to the influence of the point representing the 1987 data, which consistently plots away from the other data points. This may be due to a change in river- water chemistry since 1980 or may represent a seasonal variation in water chemistry. Figure 23 shows this same graph without the 1987 data point. The same trend is then indicated as in the other graphs.

TABLE 8: Water quality data in equivalents per million (epm).

Sampling Site	Ion Concentrations (epm) Ca	Mg	Na	K	Cl	SO4	HCO3
Surface water sites in the Scioto River							
SR1	2.94	1.56	0.87	0.12	0.96	1.73	2.79
SR2	4.64	1.89	2.48	0.24	2.62	3.96	2.93
SR3	4.59	1.89	2.44	0.23	2.59	3.75	3.11
SR4	4.59	1.89	2.44	0.24	2.59	3.54	3.03
SR5	3.99	1.97	2.04	0.20	1.78	3.75	3.02
SR6	3.99	1.97	2.00	0.20	1.75	4.16	3.02
SR7	4.04	2.06	2.09	0.20	1.75	3.75	2.97
SR8	4.04	1.97	2.09	0.21	1.72	3.54	2.97
SR9	4.34	2.06	2.00	0.21	1.80	3.96	2.92
SR10	4.09	1.97	2.04	0.19	1.75	3.96	2.88
Samples from collector wells							
CW101	4.99	2.55	0.96	0.08	1.02	2.29	4.93
CW103	5.49	2.71	0.78	0.07	0.90	2.50	5.20
CW104	5.49	2.71	0.83	0.05	0.99	2.08	5.29
Samples from the glacial outwash aquifer							
FR147	5.99	3.29	0.61	0.08	0.82	2.50	6.19
FR73	4.99	2.80	0.14	0.04	0.14	1.31	6.16
FR18	5.99	3.13	1.48	0.06	2.45	1.83	7.24
FR120	4.94	2.63	0.21	0.04	0.42	1.10	5.85
FR141	5.99	3.54	0.29	0.03	1.49	1.50	6.72
Samples from the carbonate bedrock aquifer							
FR202	5.99	3.62	1.17	0.06	0.28	3.96	6.82
FR148	1.20	4.44	2.00	0.14	1.70	4.79	0.70
FR202A	4.99	3.54	1.22	0.06	0.06	4.58	6.56
FR234A	3.64	2.88	0.78	0.05	0.76	2.02	6.72
FR246A	6.99	3.37	1.39	0.07	0.51	3.96	9.67
FR264A	9.48	4.11	2.48	0.08	2.62	3.75	10.65
FR223A	5.99	3.37	1.04	0.06	1.04	3.96	7.21

Notes:
Postscript "A" indicates samples from wells in carbonate bedrock aquifer taken in 1982

FR223A is a seep from the carbonate aquifer in a quarry wall.

Table 9
THE FOLLOWING VALUES ARE FOR THE RATIO

$$\frac{MG}{NA}$$

RECORD NUMBER	SAMPLE NAME	RATIO MG/L	RATIO MEQ/L
1	SR1	0.95	1.80
2	SR2	0.40	0.76
3	SR3	0.41	0.78
4	SR4	0.41	0.78
5	SR5	0.51	0.97
6	SR6	0.52	0.99
7	SR7	0.52	0.98
8	SR8	0.50	0.95
9	SR9	0.54	1.03
10	SR10	0.51	0.97
11	CW104	1.74	3.28
12	CW103	1.83	3.47
13	CW101	1.41	2.66
14	FR147	2.86	5.40
15	FR73	10.30	19.48
16	FR18	1.12	2.11
17	FR120	6.53	12.35
18	FR141	6.52	12.32
19	FR202	1.63	3.08
20	FR202A	1.54	2.90
21	FR148	1.17	2.22
22	FR234A	1.94	3.68
23	FR246A	1.28	2.42
24	FR264A	0.88	1.66
25	FR223SA	1.71	3.23

Key
SR=Scioto River
CW=Collector Wells
FR147, 73, 18, 120, 141 are from the glacial-outwash aquifer.
Remaining FR designated ratios are from the carbonate aquifer.

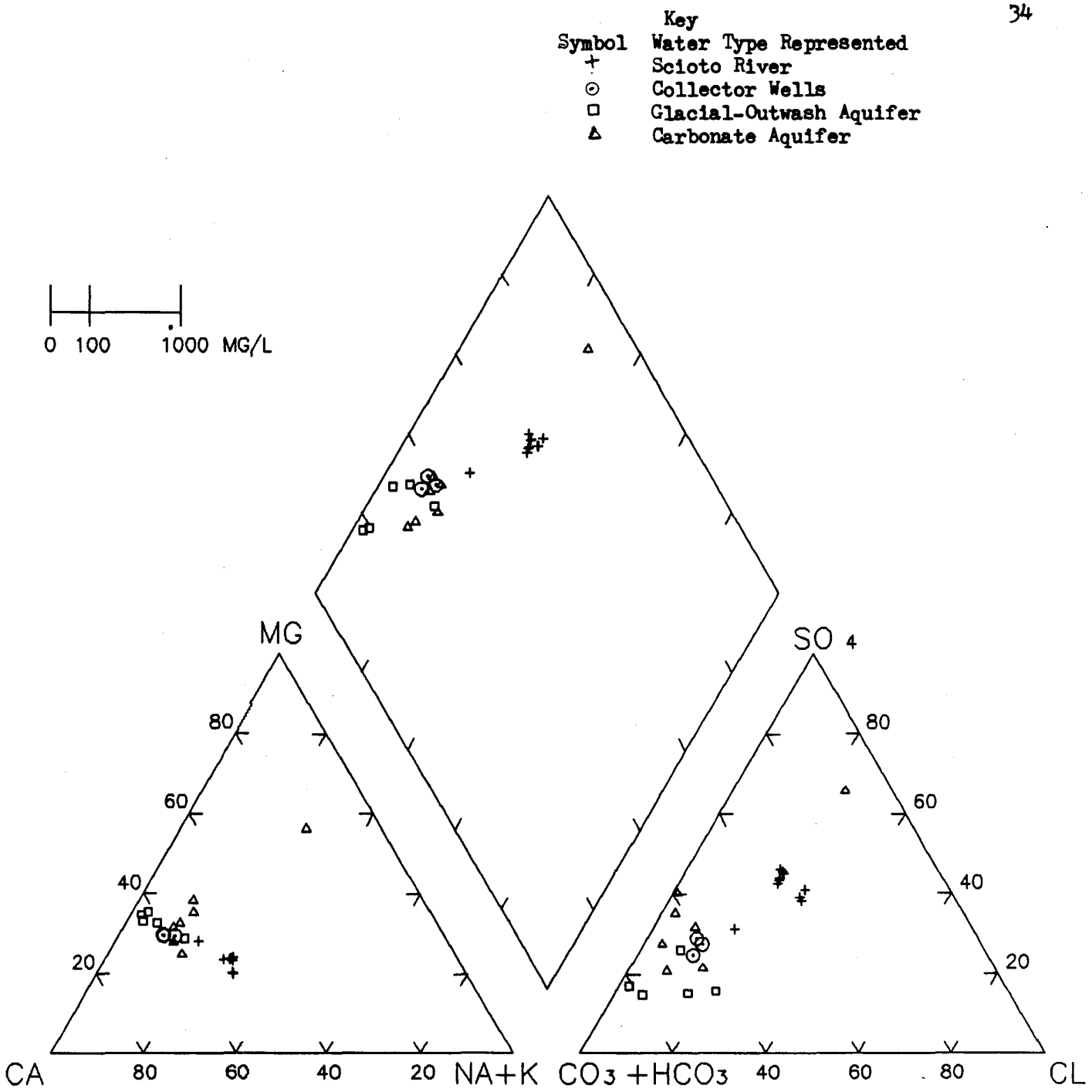


Figure 7 Piper plot of data used to analyze mixing

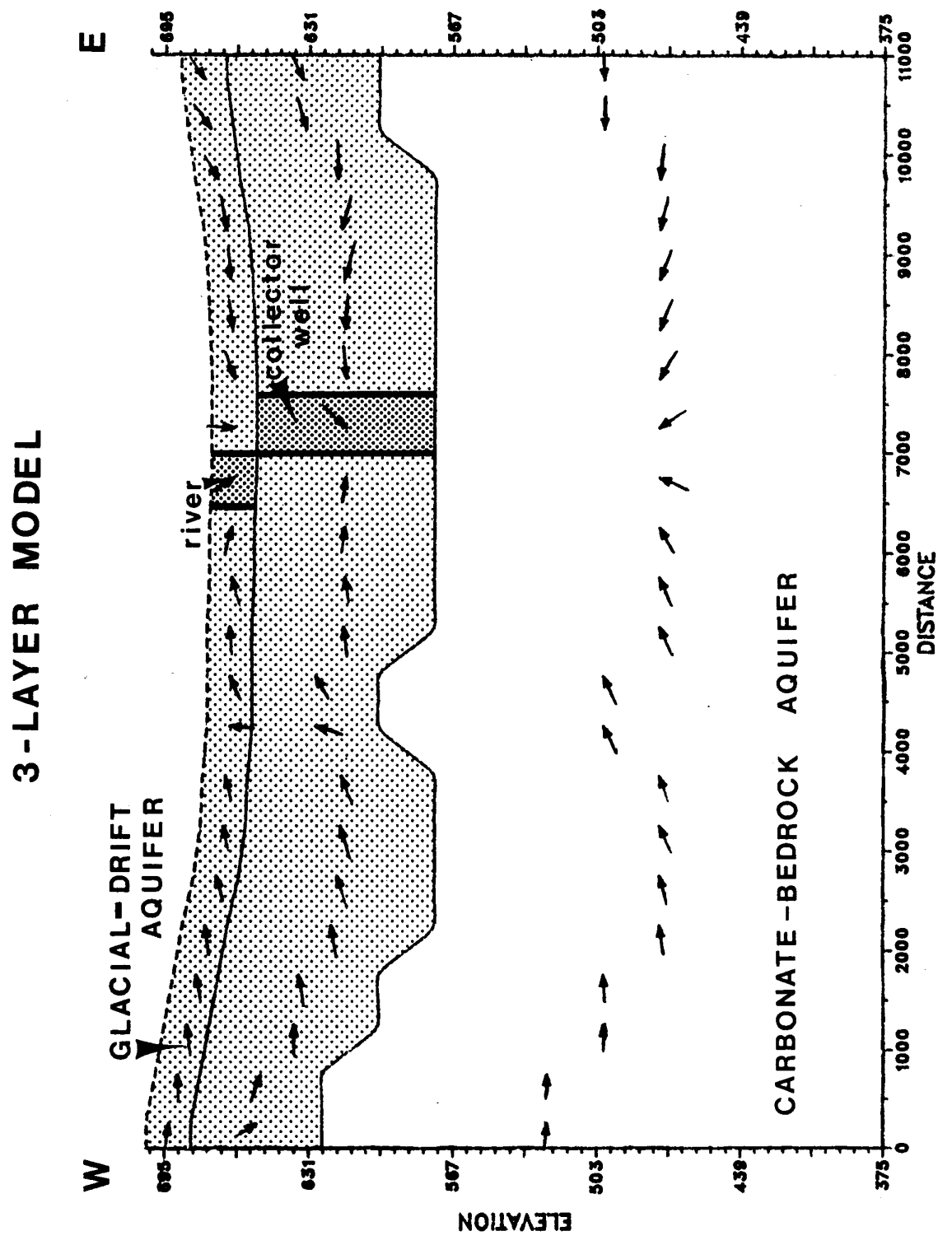


Figure 8 Flow Paths by Which Mixing Can Occur
(From Bair, Eberts, and Sheets, 1988)

Table 10 Contributions to the Water in the Collector Wells From the Scioto River Calculated Using Equation (2)

Ion	Percent Contribution
Calcium	18
Magnesium	36
Sodium	21
Potassium	13
Sulfate	33
Bicarbonate	38
Average	26

Table 11 Data Used to Evaluate Changes in Ion Concentrations With Changes in River Temperature and River Discharge

	Ion Concentrations (epm)							Water	River
	Ca	Mg	Na	k	Cl	SO4	HCO3	Temp. (C)	Discharge(cfs)
SR1	2.94	1.56	0.87	0.12	0.96	1.73	2.79	24.5	202
SR101	4.09	2.06	1.44	0.12	1.38	2.08	4.26	12.5	944
SR101A	2.89	1.48	0.87	0.07	0.79	1.52	3.11	18.5	794
SR270	4.24	2.14	1.44	0.12	1.35	2.29	4.10	11.0	944
SR270A	3.09	1.64	0.87	0.07	0.85	1.67	3.11	18.0	794
SRJP	3.94	2.06	1.31	0.11	1.33	2.02	4.26	10.0	944
SRJPA	2.99	1.64	0.87	0.07	0.79	1.62	3.28	17.5	794

	Dates of Samples
SR1	18 August 1987
SR101	20 November 1979
SR101A	19 March 1980
SR270	20 November 1979
SR270A	19 March 1980
SRJP	20 November 1979
SRJPA	19 March 1980

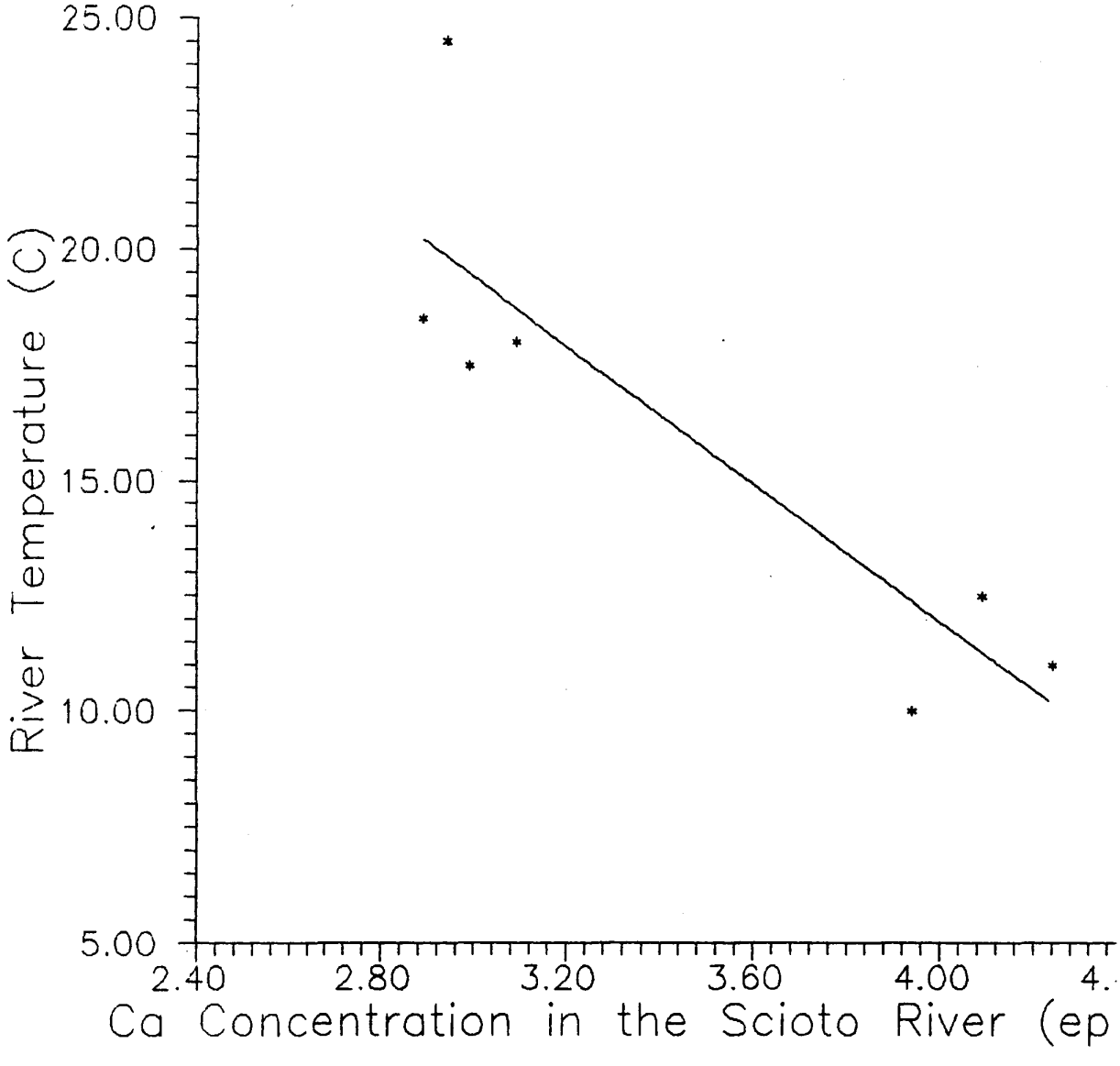

25.00
20.00
15.00
10.00
5.00
River Temperature (C)
2.40
2.80
3.20
3.60
4.00
4.
Ca Concentration in the Scioto River (ep

Figure 9

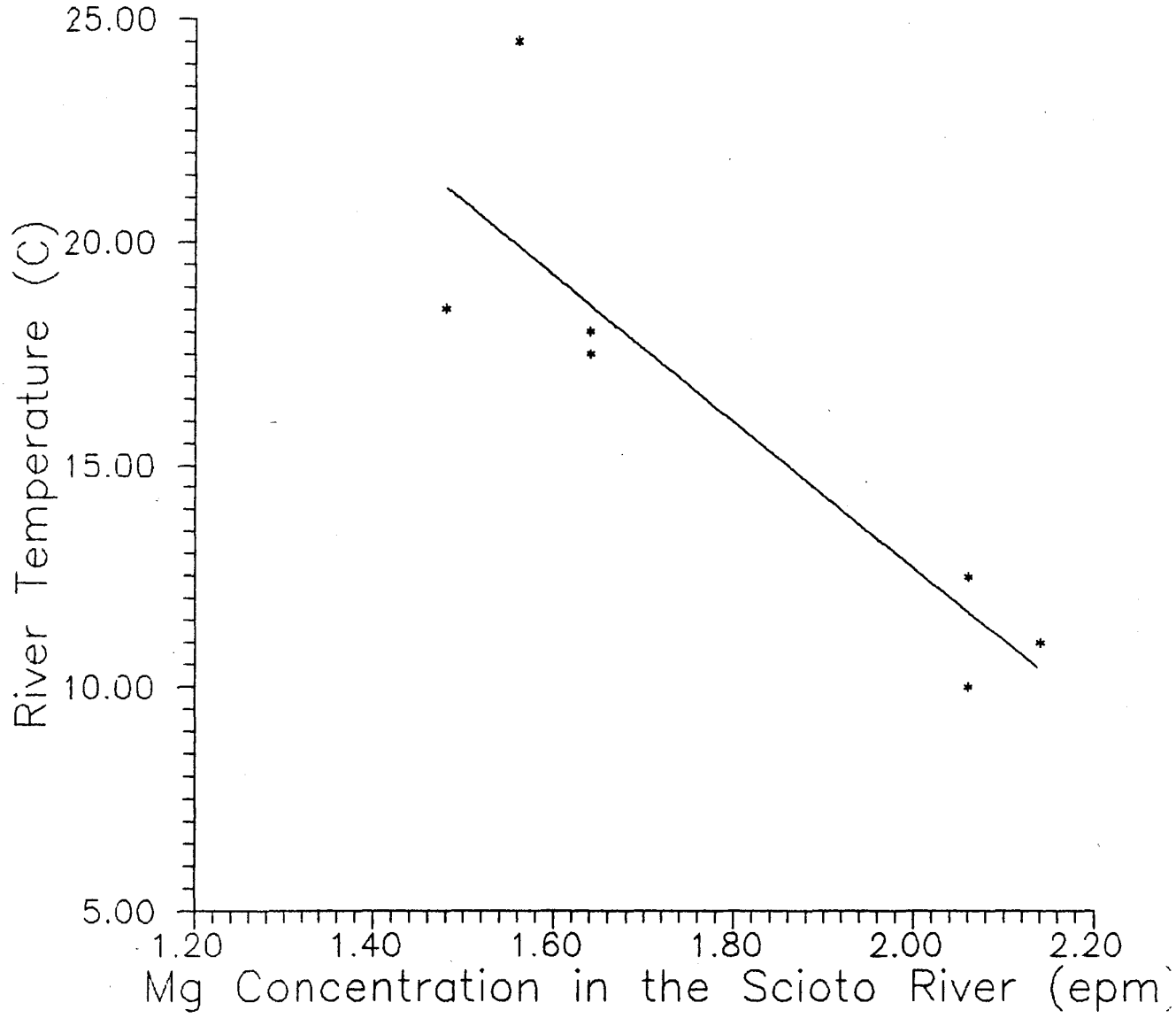

25.00
20.00
15.00
10.00
5.00
River Temperature (C)
1.20
1.40
1.60
1.80
2.00
2.20
Mg Concentration in the Scioto River (epm)

Figure 10

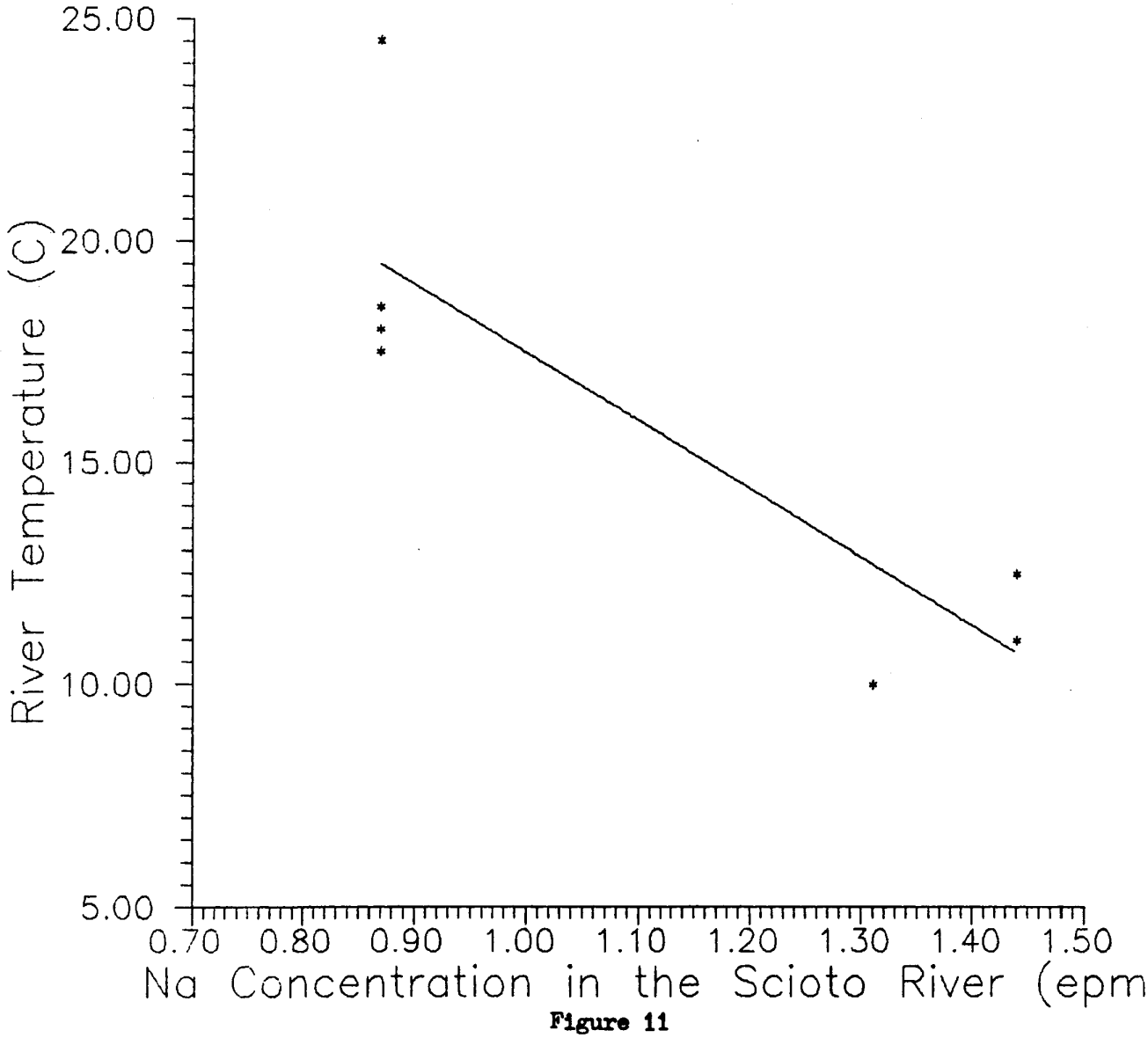

25.00
20.00
15.00
10.00
5.00
River Temperature (C)
0.70
0.80
0.90
1.00
1.10
1.20
1.30
1.40
1.50
Na Concentration in the Scioto River (epm

Figure 11

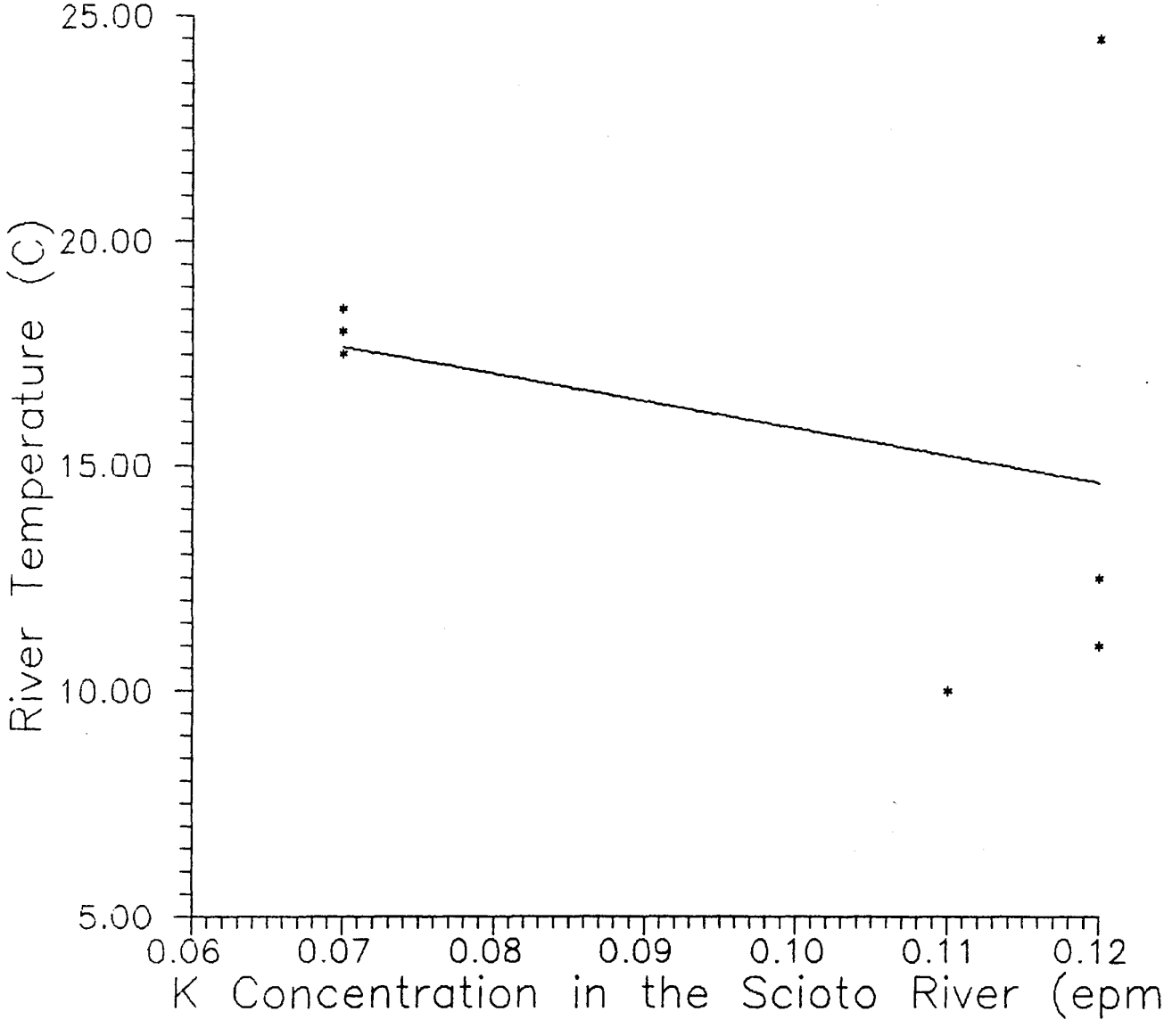

25.00
20.00
15.00
10.00
5.00
River Temperature (C)
0.06
0.07
0.08
0.09
0.10
0.11
0.12
K Concentration in the Scioto River (epm)

Figure 12

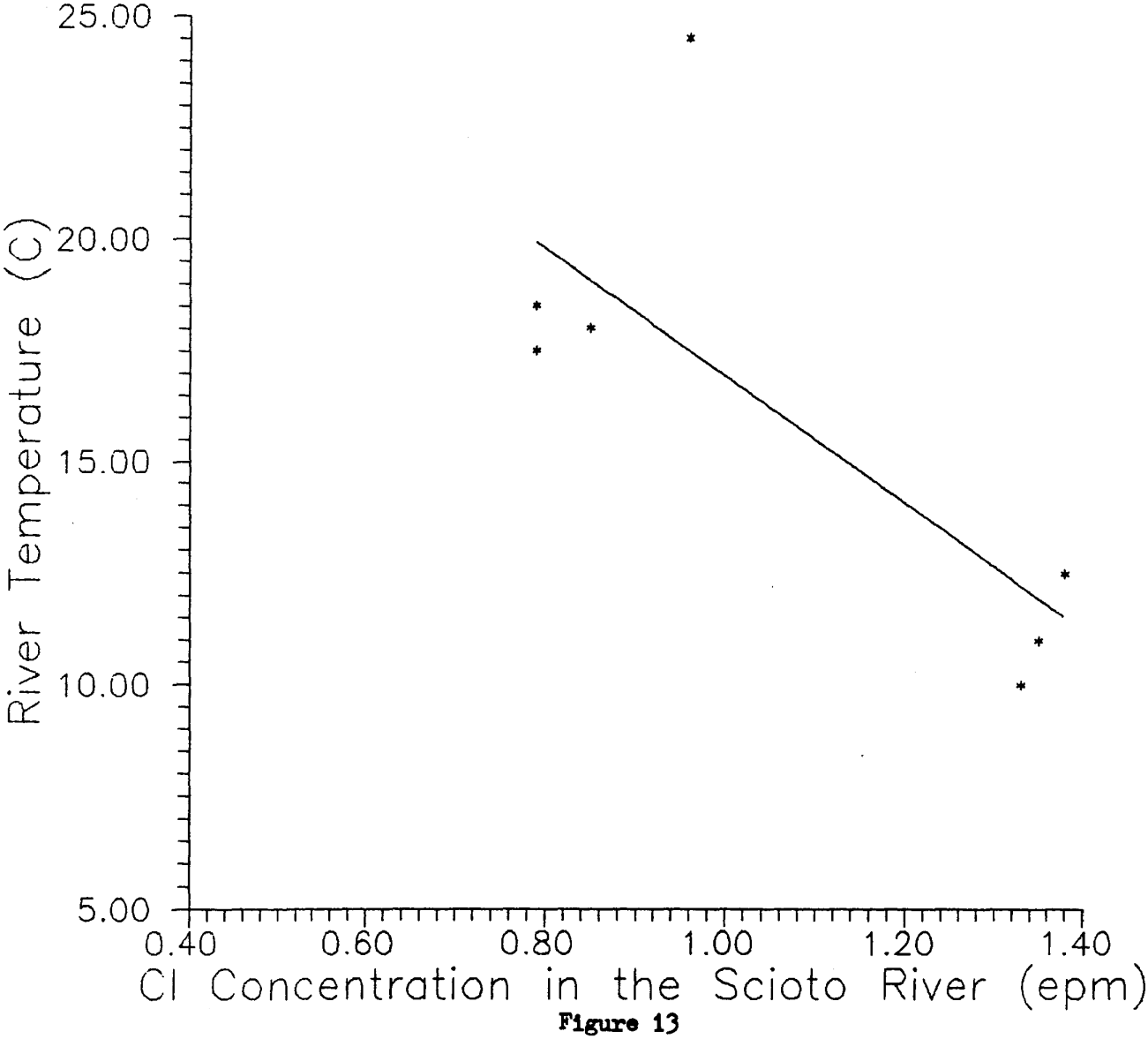

25.00
20.00
15.00
10.00
5.00
River Temperature (C)
0.40
0.60
0.80
1.00
1.20
1.40
Cl Concentration in the Scioto River (epm)

Figure 13

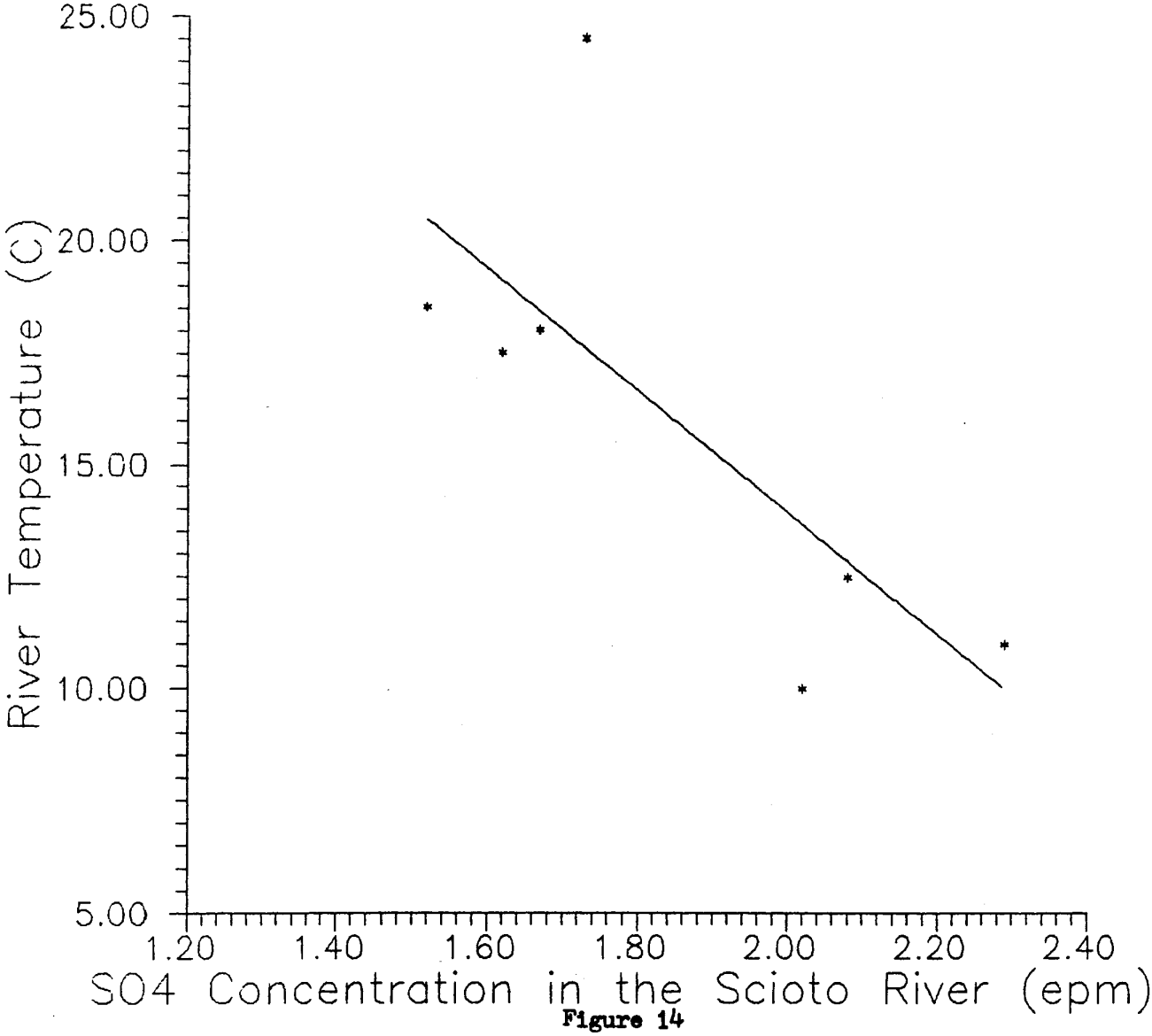

25.00
20.00
15.00
10.00
5.00
River Temperature (C)
1.20
1.40
1.60
1.80
2.00
2.20
2.40
SO4 Concentration in the Scioto River (epm)

Figure 14

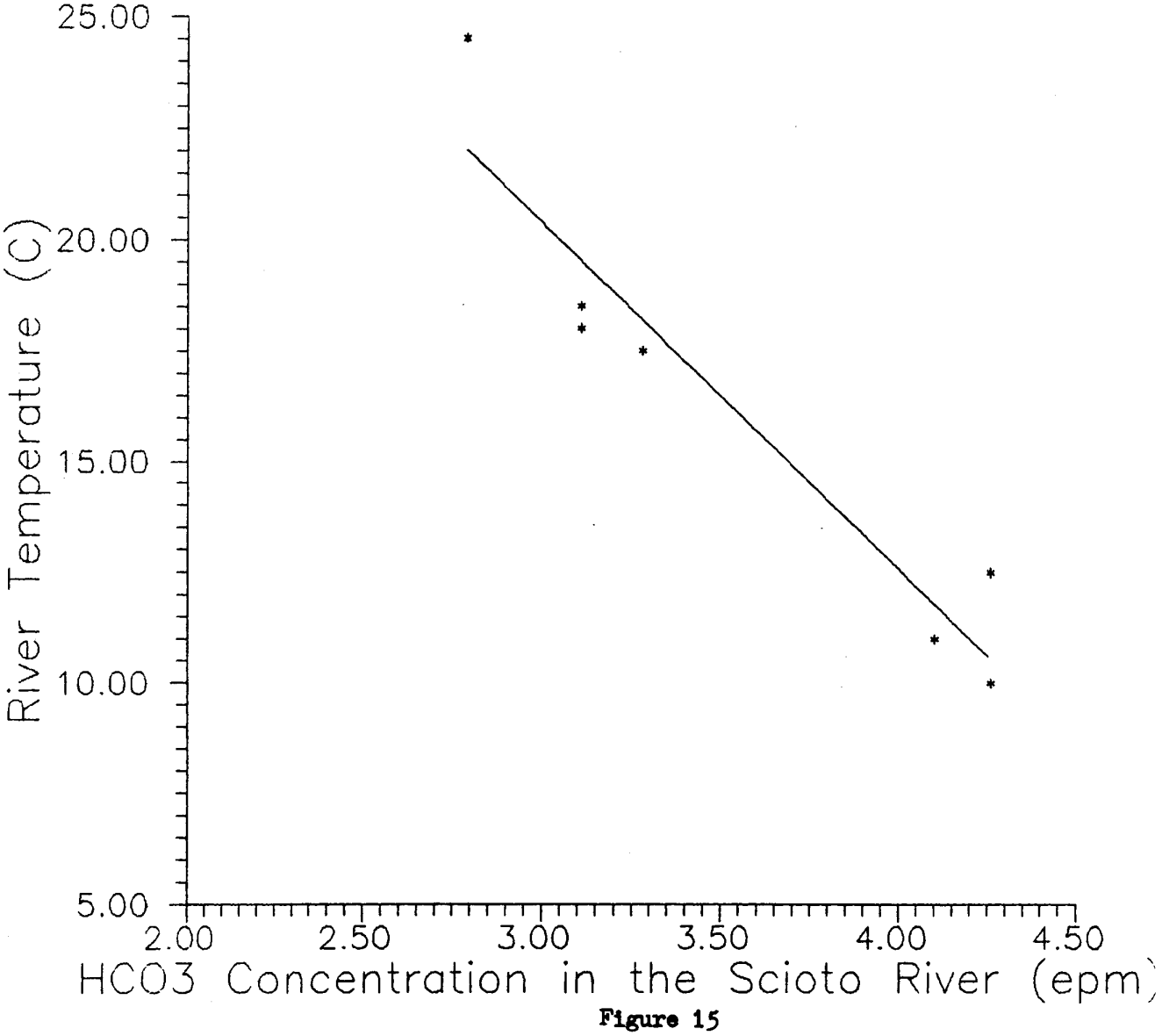

25.00
20.00
15.00
10.00
5.00
River Temperature (C)
2.00
2.50
3.00
3.50
4.00
4.50
HCO3 Concentration in the Scioto River (epm)

Figure 15

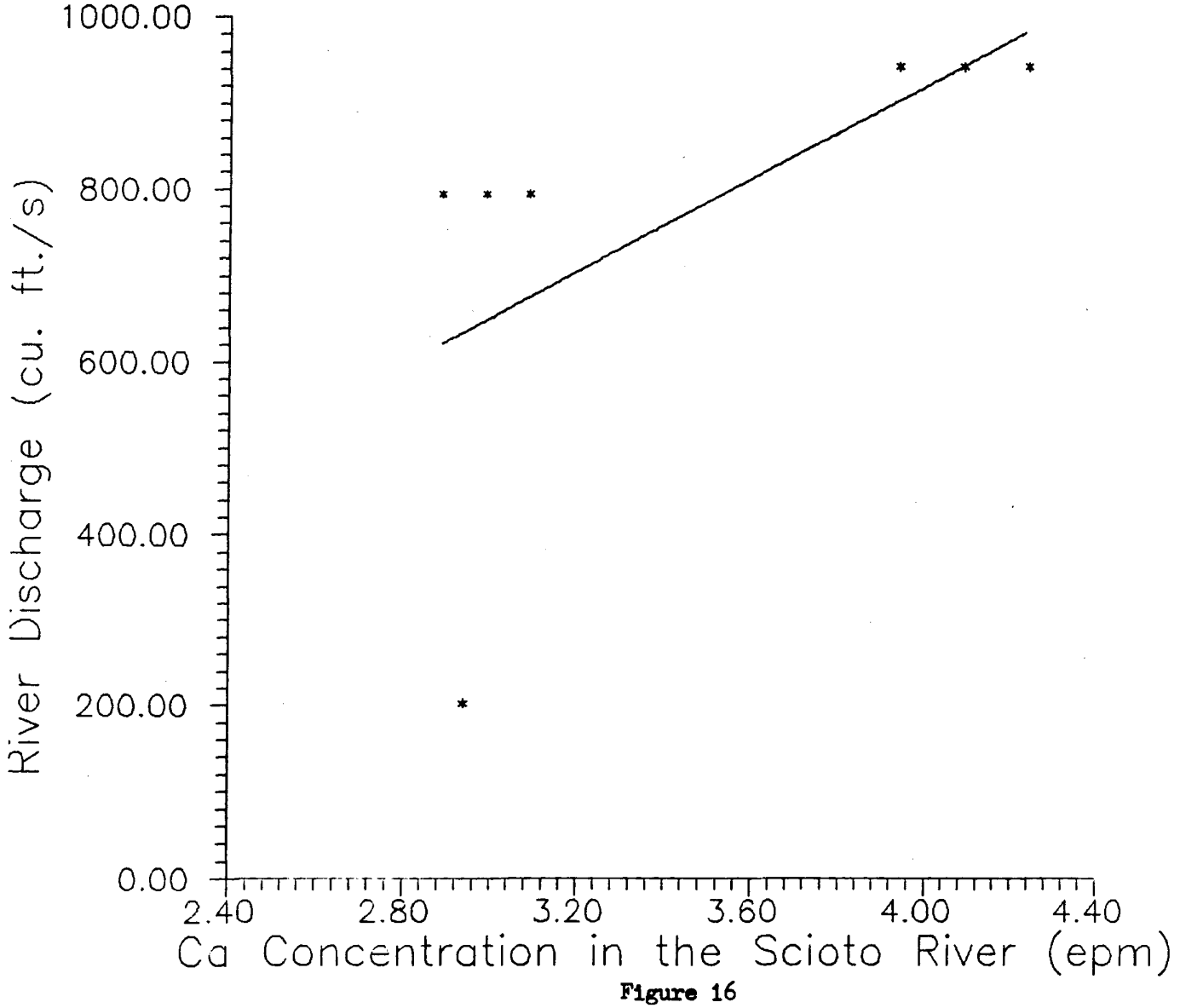

1000.00
800.00
600.00
400.00
200.00
0.00
River Discharge (cu. ft./s)
2.40
2.80
3.20
3.60
4.00
4.40
Ca Concentration in the Scioto River (epm)

Figure 16

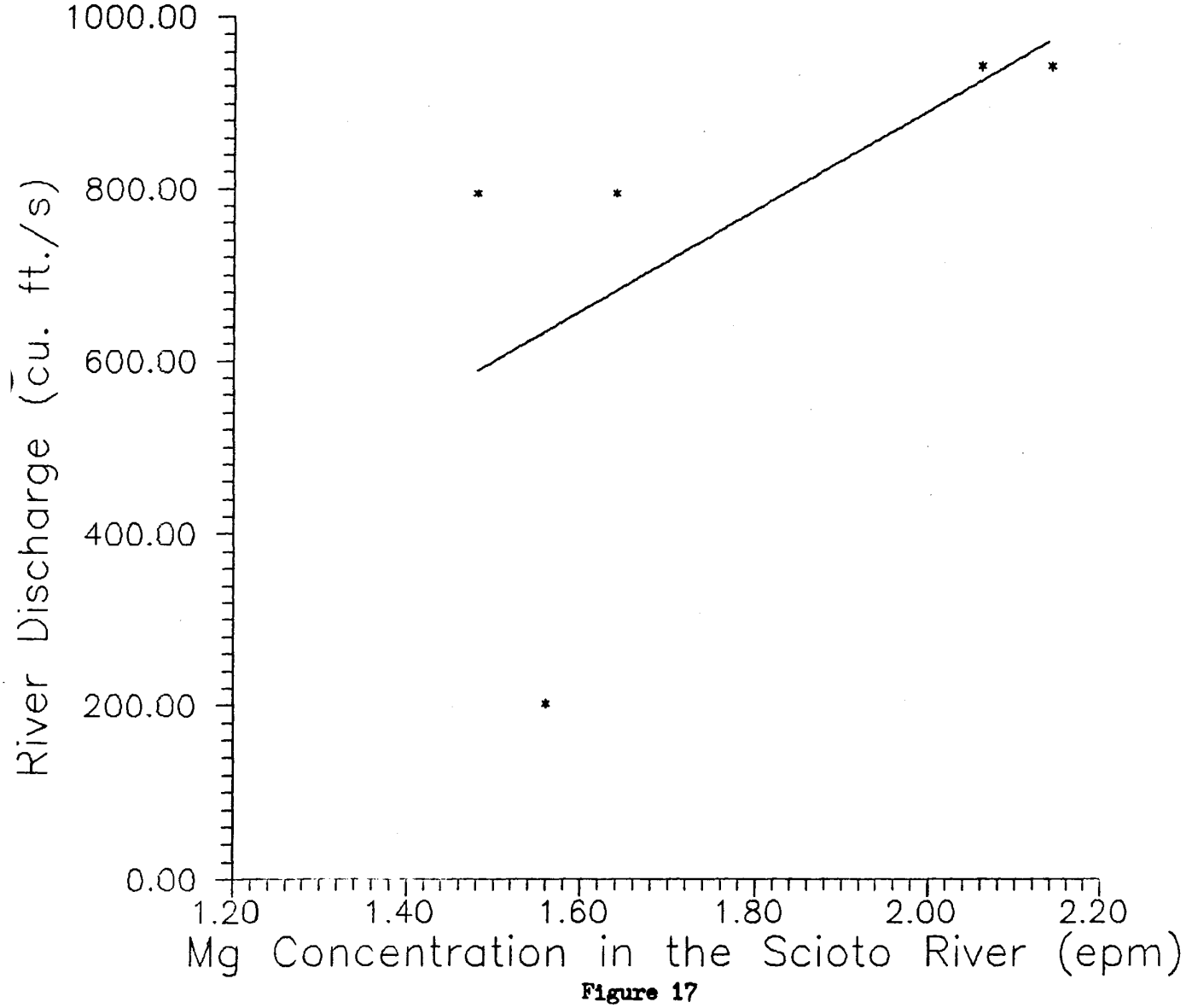

1000.00
800.00
600.00
400.00
200.00
0.00
River Discharge (cu. ft./s)
1.20
1.40
1.60
1.80
2.00
2.20
Mg Concentration in the Scioto River (epm)

Figure 17

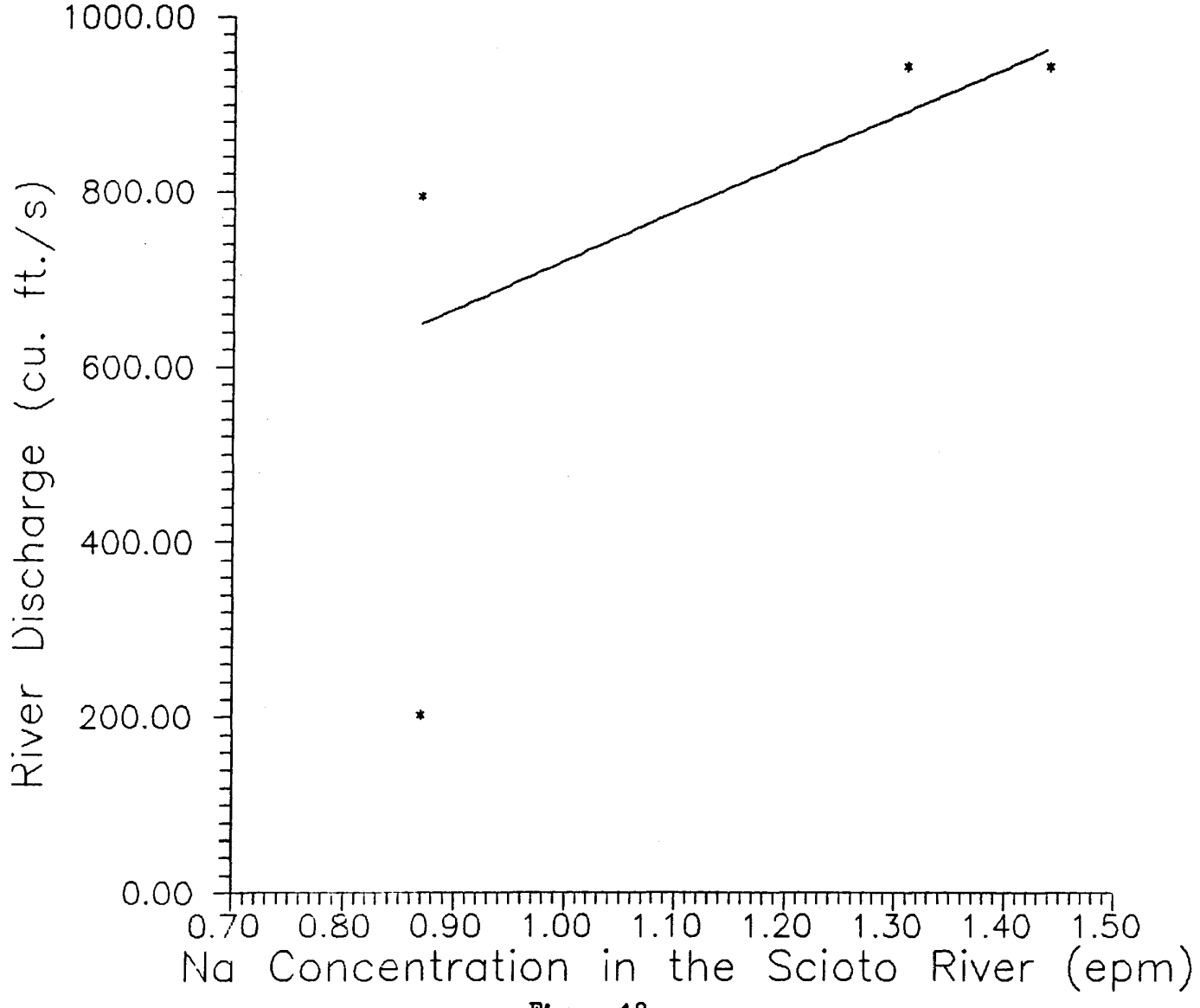

1000.00
800.00
600.00
400.00
200.00
0.00
River Discharge (cu. ft./s)
0.70
0.80
0.90
1.00
1.10
1.20
1.30
1.40
1.50
Na Concentration in the Scioto River (epm)

Figure 18

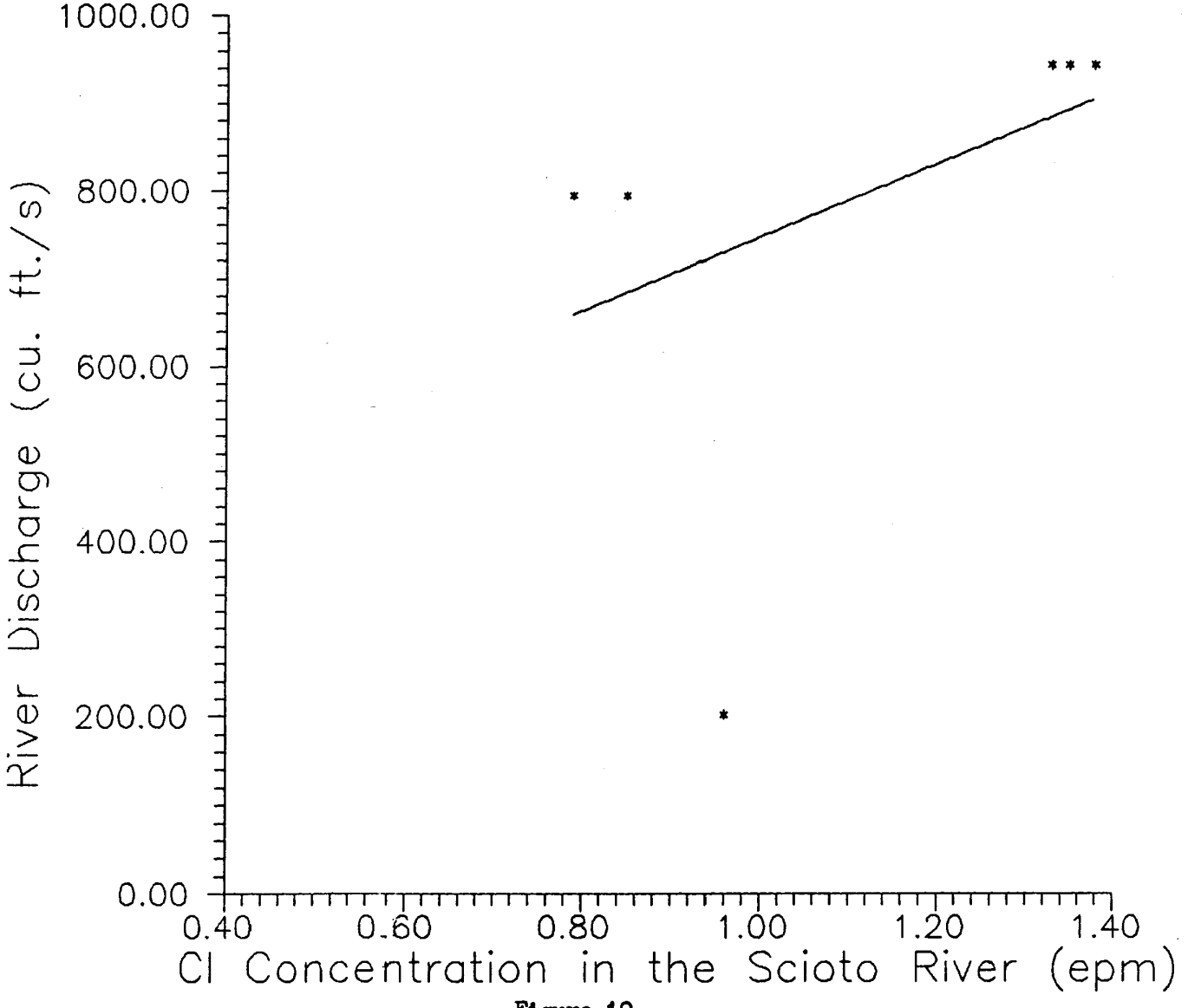

1000.00
800.00
600.00
400.00
200.00
0.00
River Discharge (cu. ft./s)
0.40
0.60
0.80
1.00
1.20
1.40
Cl Concentration in the Scioto River (epm)

Figure 19

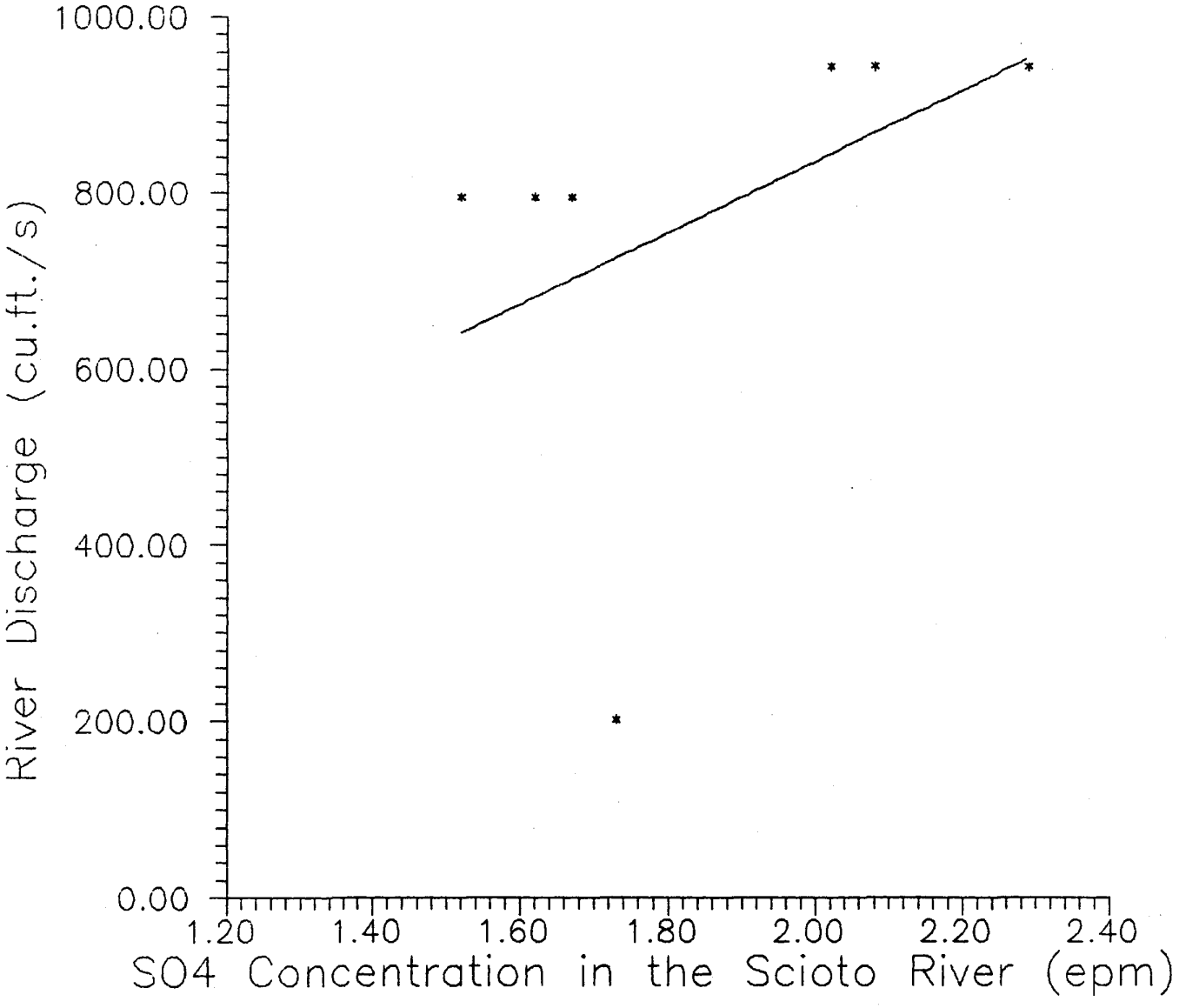

1000.00
800.00
600.00
400.00
200.00
0.00
River Discharge (cu.ft./s)
1.20
1.40
1.60
1.80
2.00
2.20
2.40
SO4 Concentration in the Scioto River (epm)

Figure 20

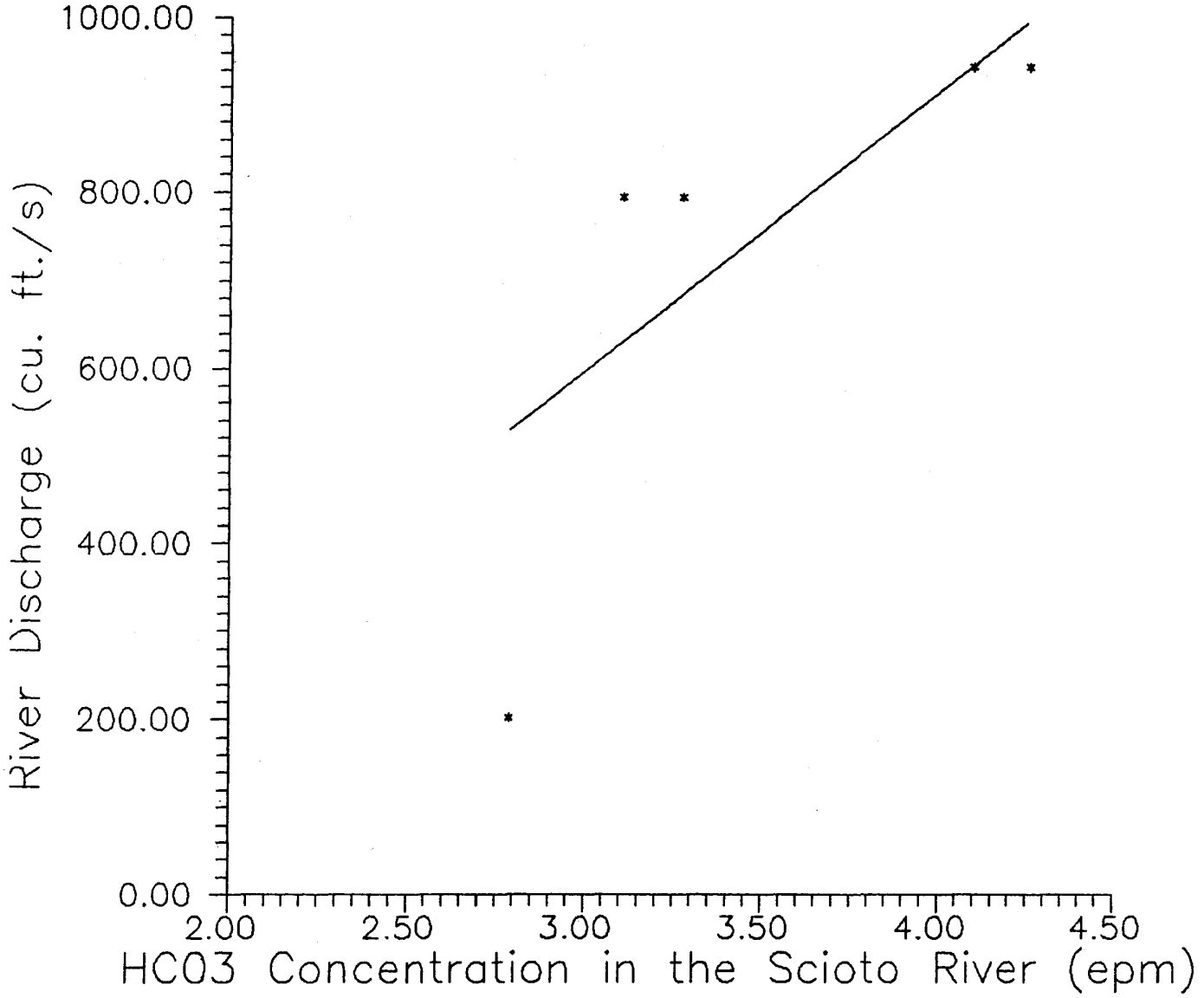

1000.00
800.00
600.00
400.00
200.00
0.00
River Discharge (cu. ft./s)
2.00
2.50
3.00
3.50
4.00
4.50
HCO3 Concentration in the Scioto River (epm)

Figure 21

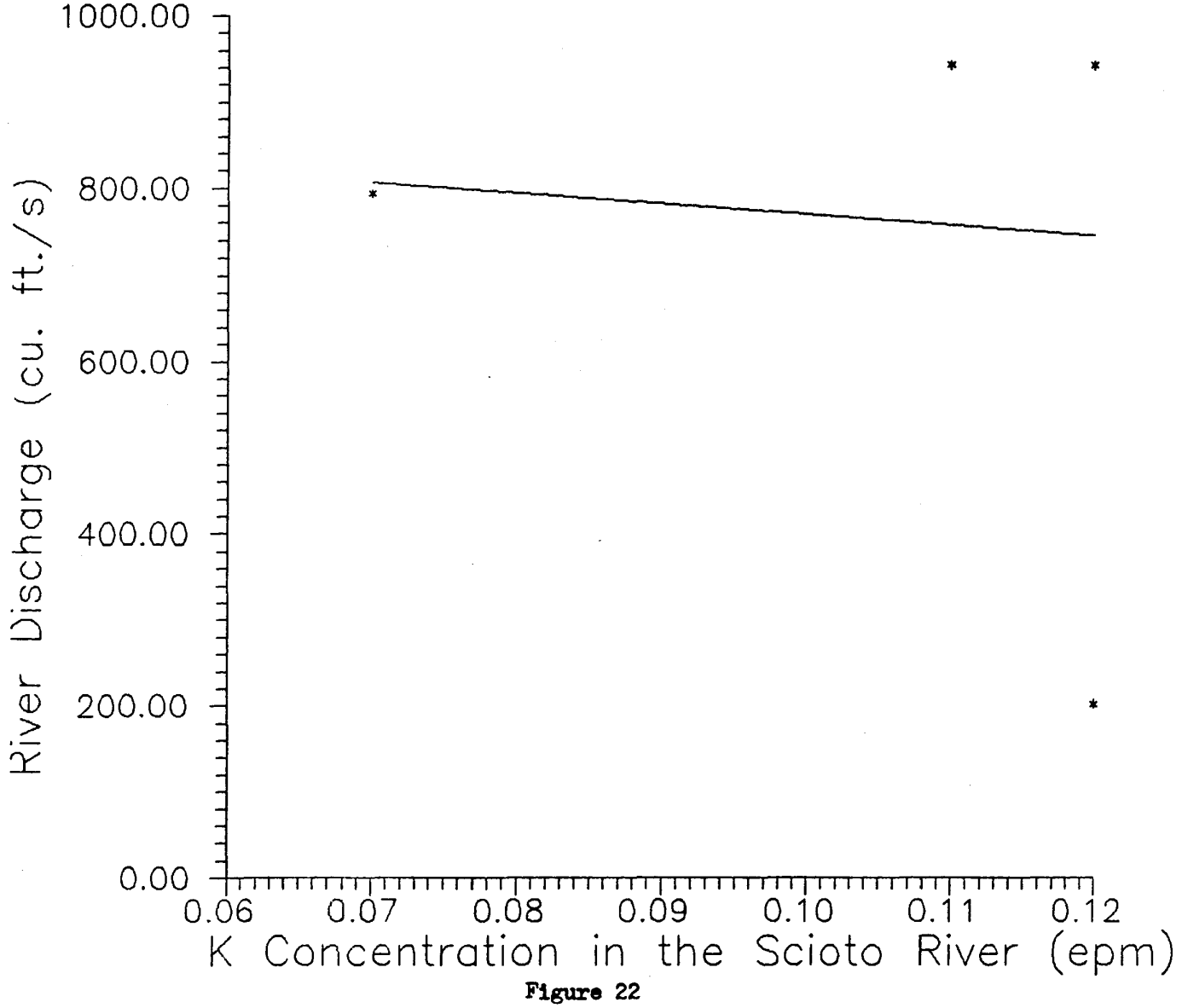

1000.00
800.00
600.00
400.00
200.00
0.00
River Discharge (cu. ft./s)
0.06
0.07
0.08
0.09
0.10
0.11
0.12
K Concentration in the Scioto River (epm)

Figure 22

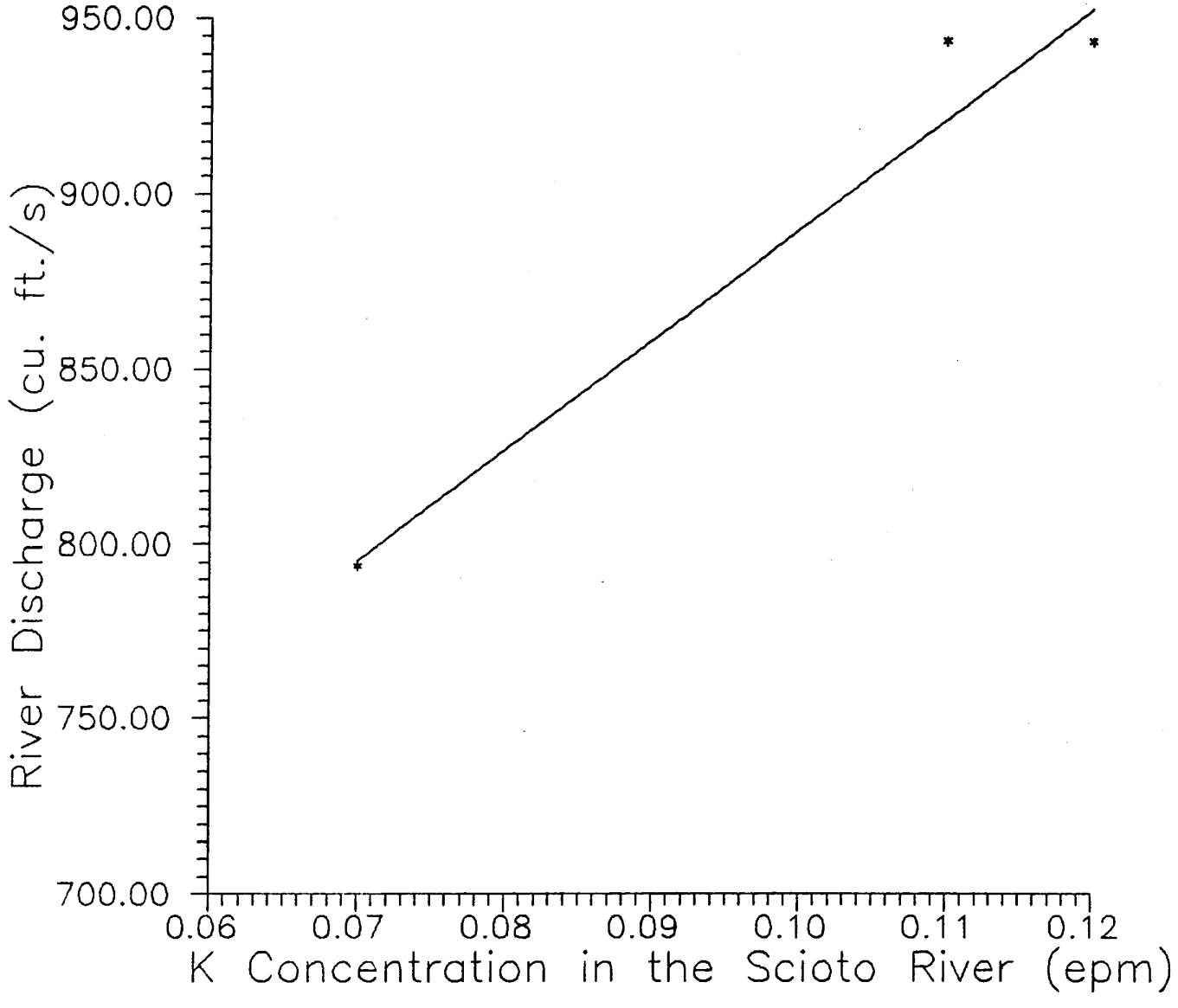

950.00
900.00
850.00
800.00
750.00
700.00
River Discharge (cu. ft./s)
0.06
0.07
0.08
0.09
0.10
0.11
0.12
K Concentration in the Scioto River (epm)

Figure 23

RECOMMENDATIONS FOR FURTHER STUDIES

In order to evaluate temporal variations in the relative contributions of the potential source waters to the water in the collector wells, a more comprehensive study including regular sampling and water-quality testing throughout the year needs to be conducted. This sampling should encompass a wide range of water temperatures and river stages. A study of the variations in relative contributions with changes in pumping rate and a study of temporal variations in streambed permeability would allow all of the relevant factors to be considered to understand the hydrogeology of the area better.

References Cited

de Roche, J. T., 1985. Hydrogeology and Effects of Landfills on Ground-Water Quality, Southern Franklin County, Ohio: U. S. Geological Survey Water Resources Investigations Report 85-4222, 58p.

de Roche, J. T. and A. C. Razem, 1984. Water Quality of A Stream-Aquifer System, Southern Franklin County, Ohio: U. S. Geological Survey Water Resources Investigations Report 84-4238, 44p.

Eberts, S. M., 1987. Potential Effects of Chemical Spills or Cessation of Quarry Dewatering on a Municipal Ground-Water Supply, Southern Franklin County, Ohio: The Ohio State University, Department of Geology and Mineralogy, Unpublished Master's Thesis, 104p.

Moreno, R. M., 1988. An Investigation of the Hydraulic Conductivity of the Scioto River Streambed at the South Well Field, Southern Franklin County, Ohio: The Ohio State University, Department of Geology and Mineralogy, Unpublished Senior Thesis, 41p.

Norris, S. E. , 1986. Reevaluation of the Stilson Pump Test Data, Unpublished File, U. S. Geological Survey, Columbus, Ohio.

Schmidt, J. J. and R. S. Goldthwait, 1958. The Ground-Water Resources of Franklin County, Ohio: Ohio Department of Natural Resources Division of Water Bulletin 30, 97p.

Sheets, R. A., E. S. Bair, and S. M. Eberts, 1988. Determination of Flow Paths and Traveltimes from Hypothetical Spill Sites Surrounding a Municipal Well Field.

Stilson, A. E. and Associates, 1976. Report of the Development of a Groundwater Supply in the South Well Field for the City of Columbus, Ohio, Division of Water, Appendix by F. H. Klaer and Associates, Hydrological Report on South Well Field Exploration and Testing Programs, 1974-1975.

Stilson, A. E. and Associates, 1977. Report of the Development of a Groundwater Supply in the South Well Field, Addendum No. 1, Well Site 115A, Report to the City of Columbus, Ohio, Division of Water, Appendix by F. H. Klaer Jr. and Associates, entitled same.

U. S. Geological Survey, 1987. Water Resources Data for Ohio Water Year 1987, Volume 2.

Weiss, E. J. and A. C. Razem, 1980. A Model for Flow Through a Glacial- Outwash Aquifer in Southeast Franklin County, Ohio: U. S. Geological Survey Water Resources Investigations 80-56, 27p.

APPENDIX 1

Mixing Diagrams Figures 24-44

Table 12 Key to Mixing Diagrams

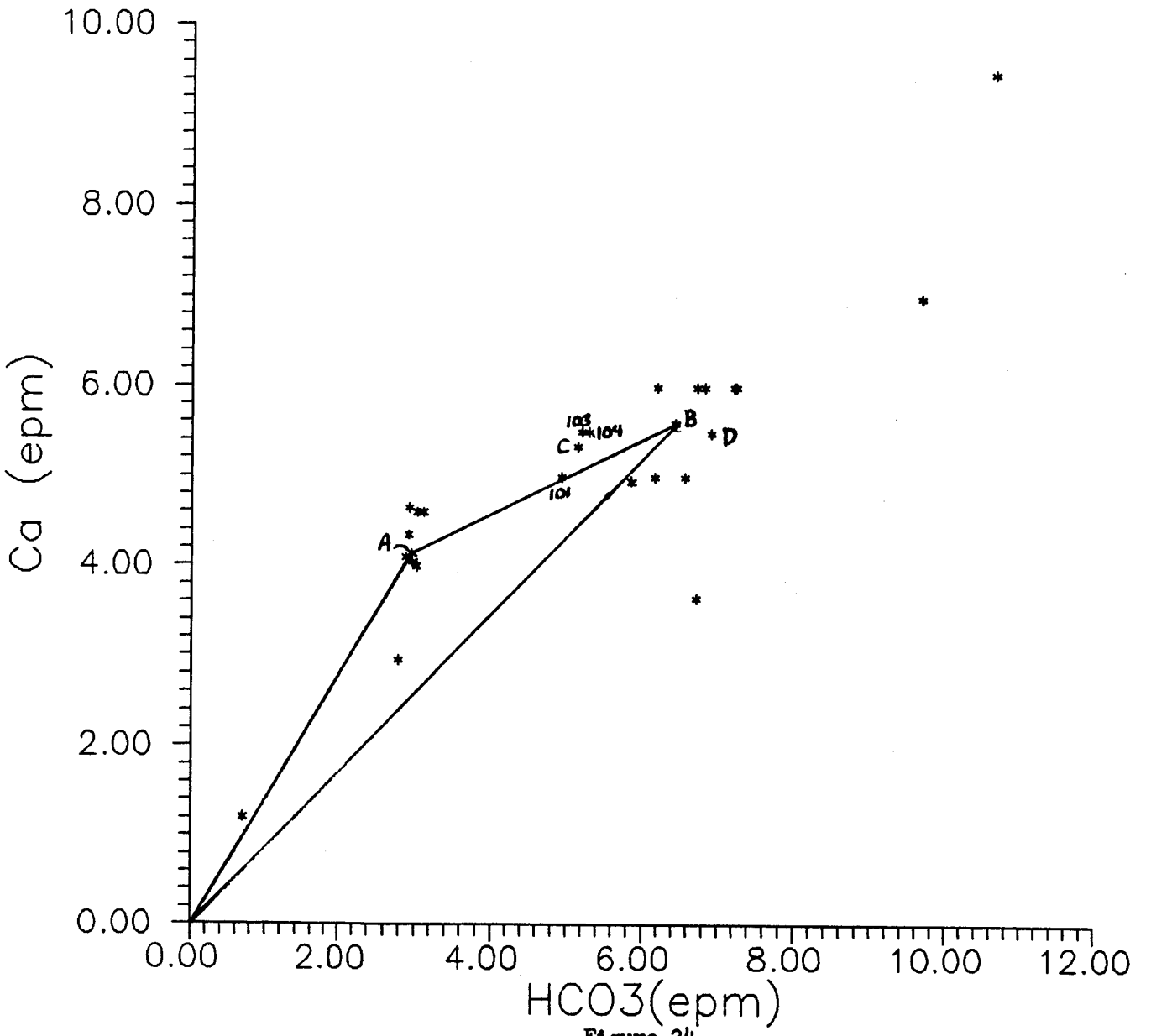
Letters A, B, C, and D, represent the Average Ionic Concentrations From Table 7 for Their Respective Water Source

A= Scioto River

B= Glacial-Outwash Aquifer

C= Collector Wells

D= Carbonate Aquifer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8.00
6.00
4.00
2.00
0.00
Ca (epm)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
HCO3(epm)
A
B
C
D
103
104
101

Figure 24

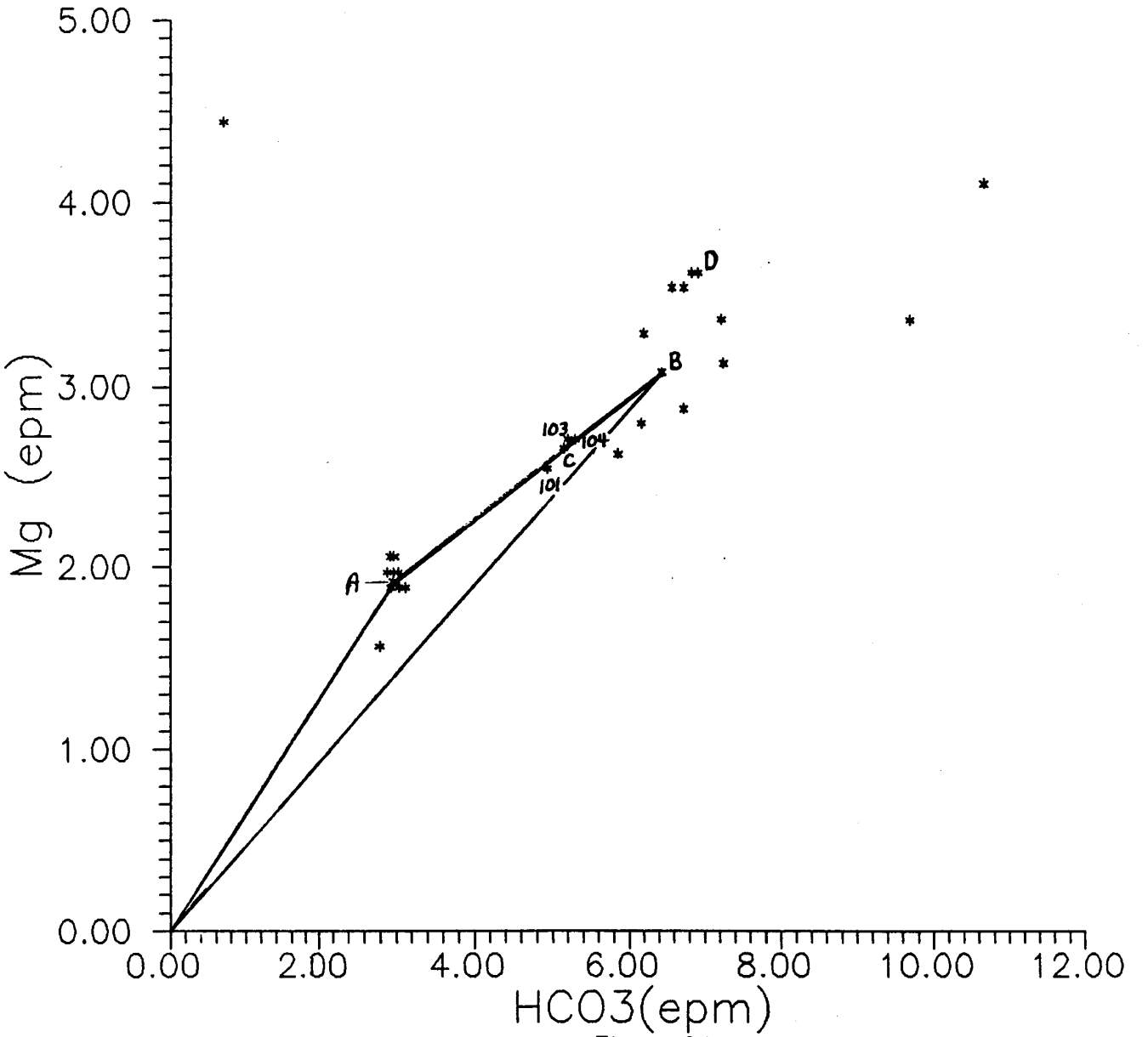

5.00
4.00
3.00
2.00
1.00
0.00
Mg (epm)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
HCO3(epm)
A
B
C
D
101
103
104

Figure 25

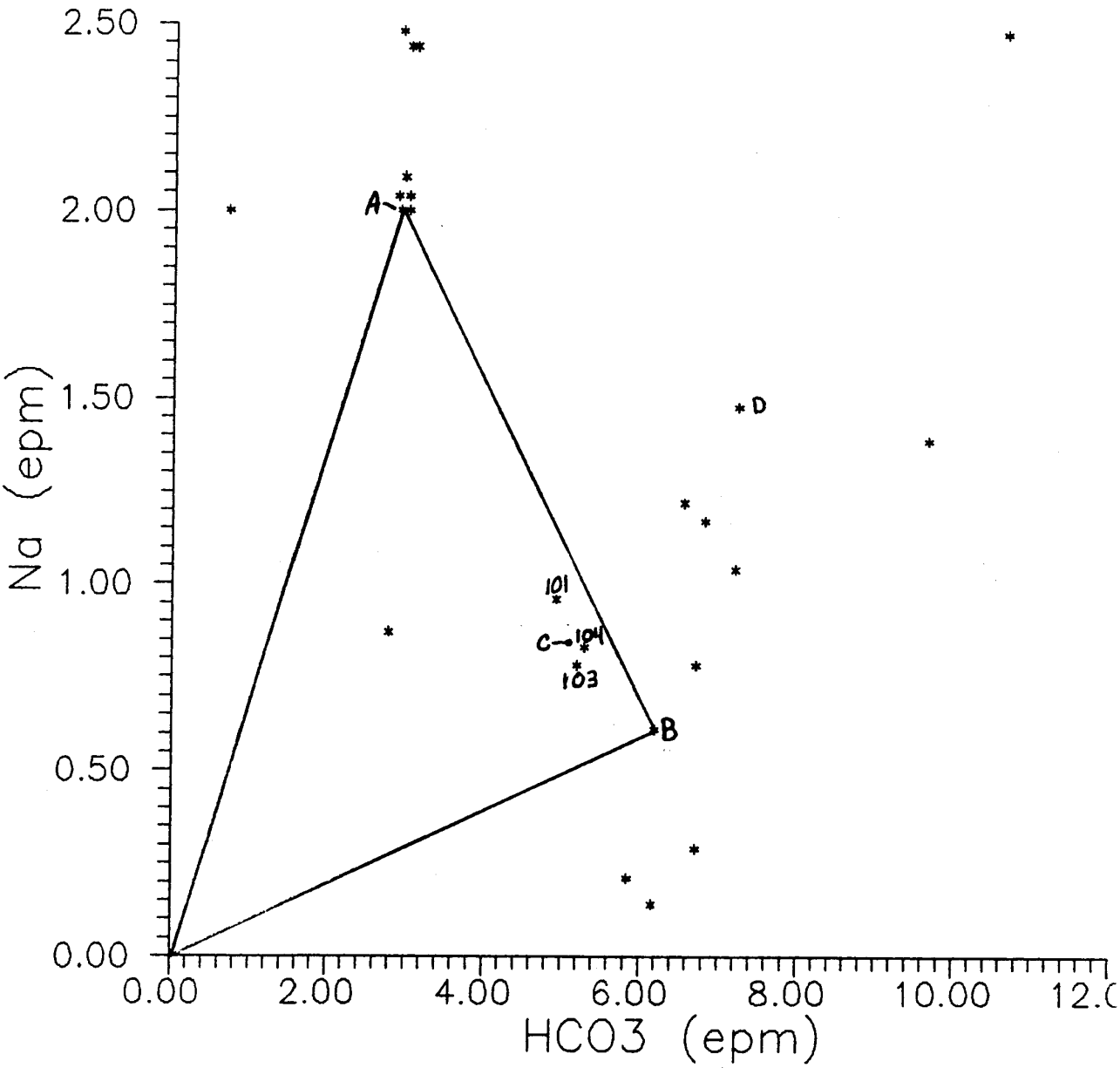

2.50
2.00
1.50
1.00
0.50
0.00
Na (epm)
0.00
2.00
4.00
6.00
8.00
10.00
12.0
HCO3 (epm)
A
B
C
D
101
104
103

Figure 26

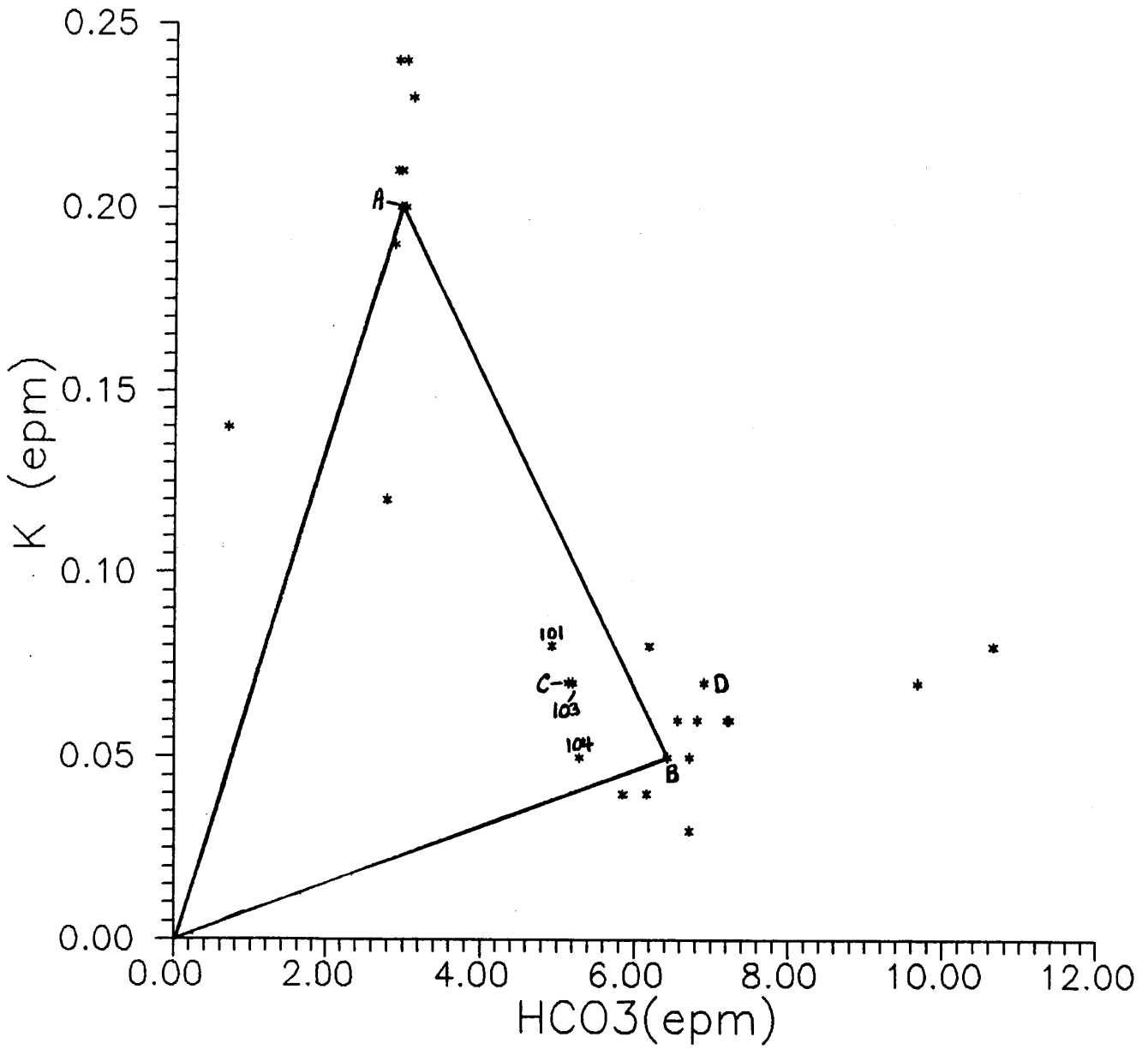

0.25
0.20
0.15
0.10
0.05
0.00
K (epm)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
HCO3(epm)
A
B
C
D
101
103
104

Figure 27

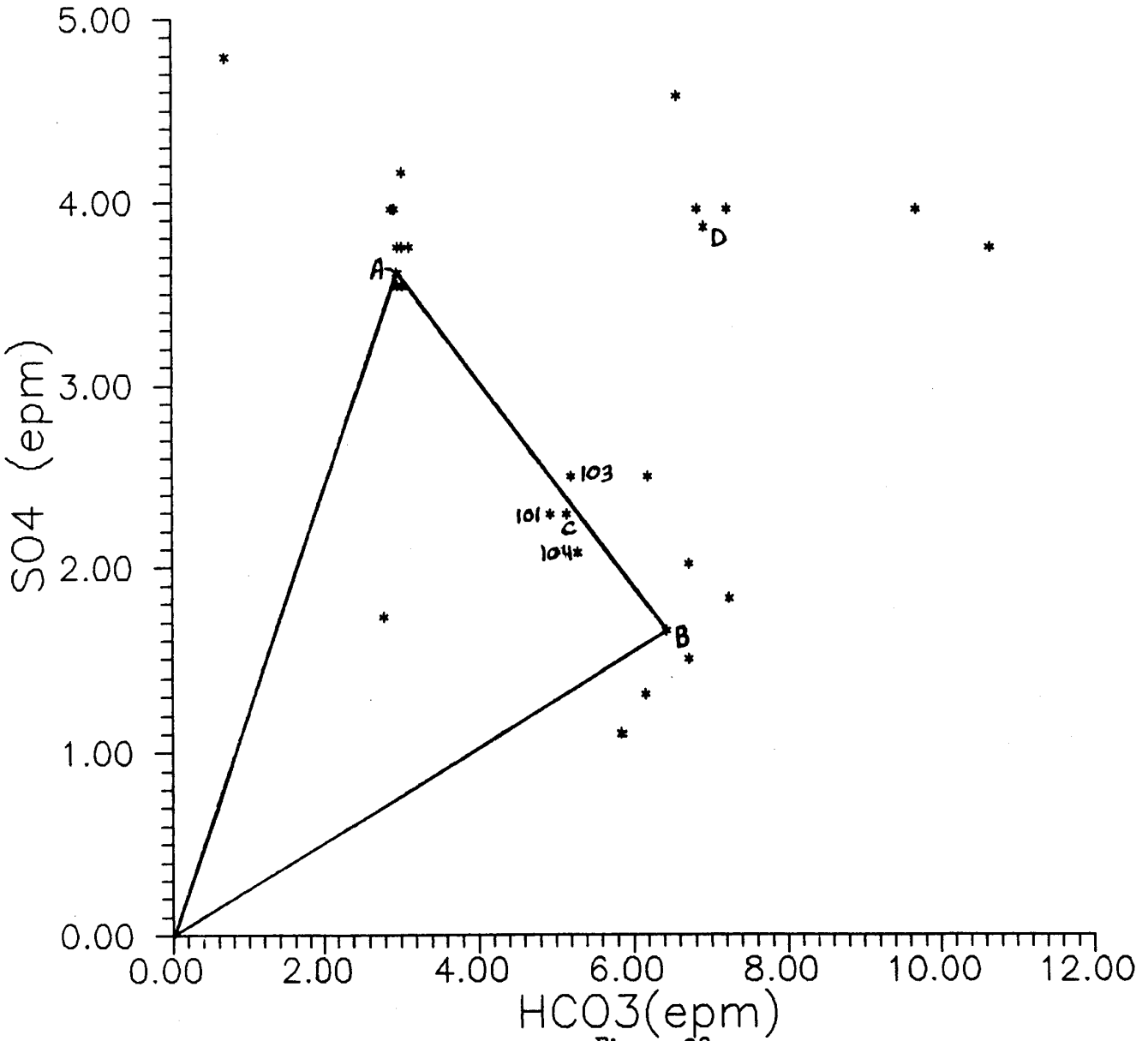
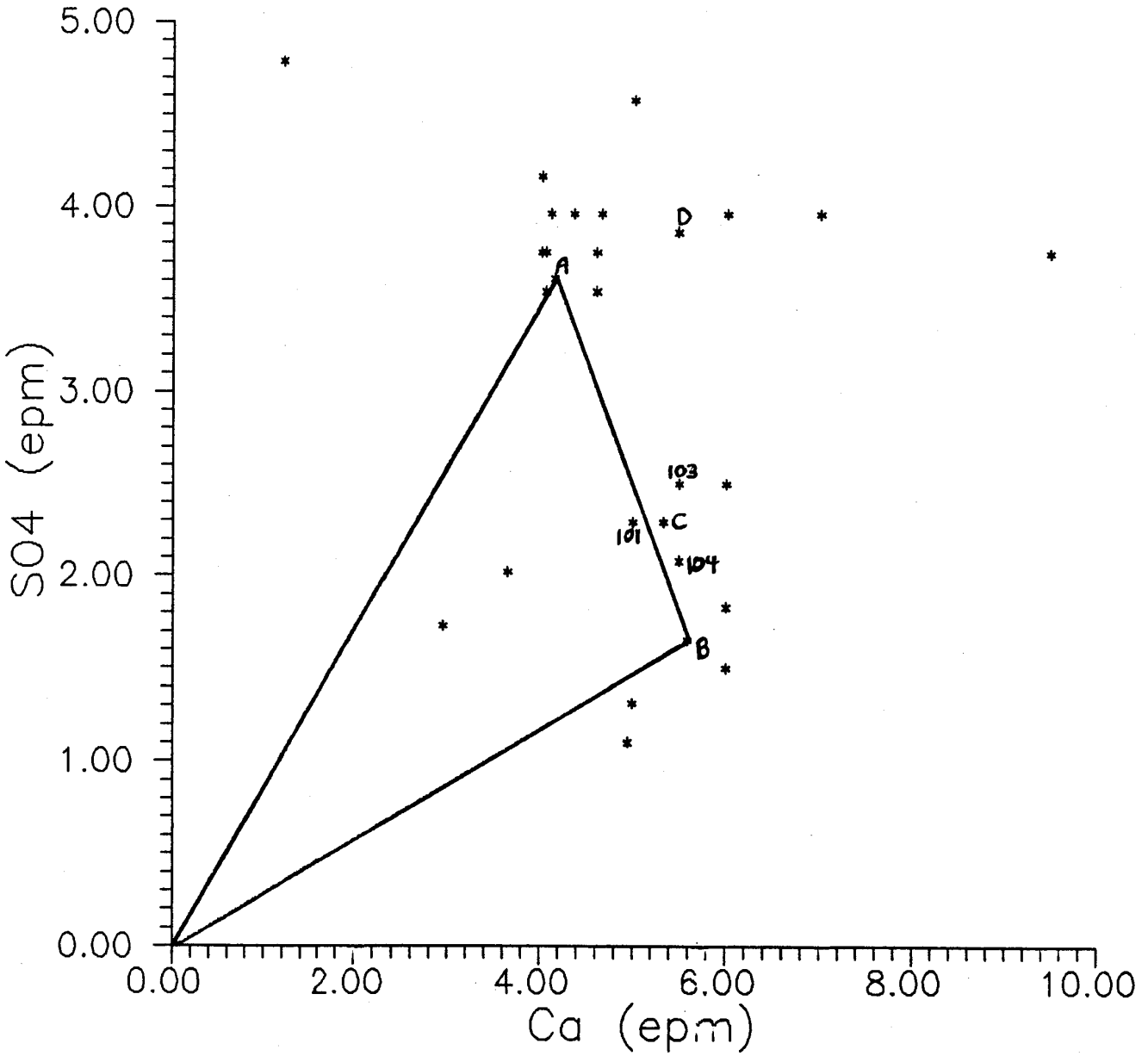

5.00
4.00
3.00
2.00
1.00
0.00
SO4 (epm)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
HCO3(epm)
A
B
C
D
103
101
104

Figure 28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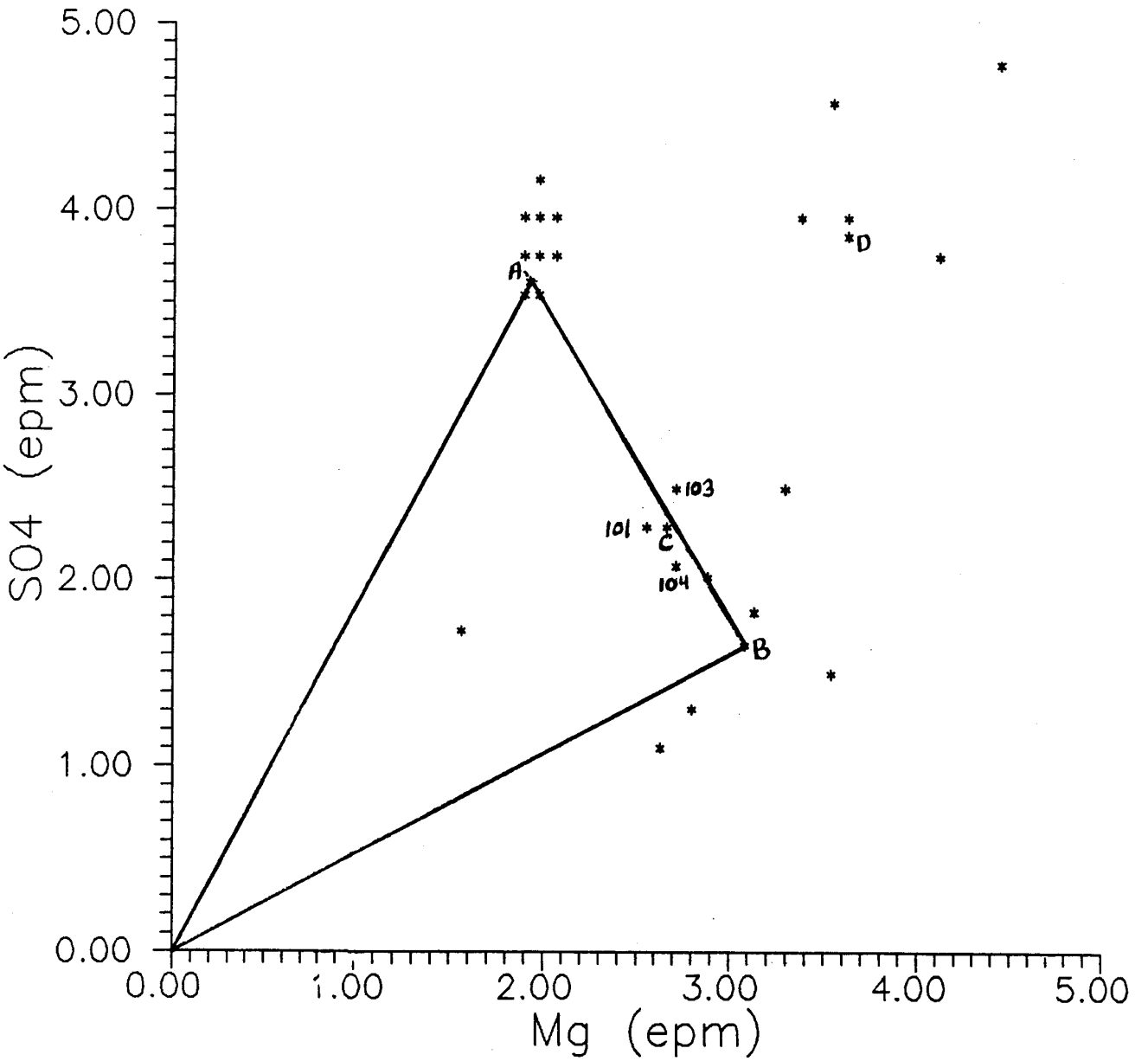
4.00
3.00
2.00
1.00
0.00
SO4 (epm)
0.00
2.00
4.00
6.00
8.00
10.00
Ca (epm)
A
B
C
D
101
103
104

Figure 29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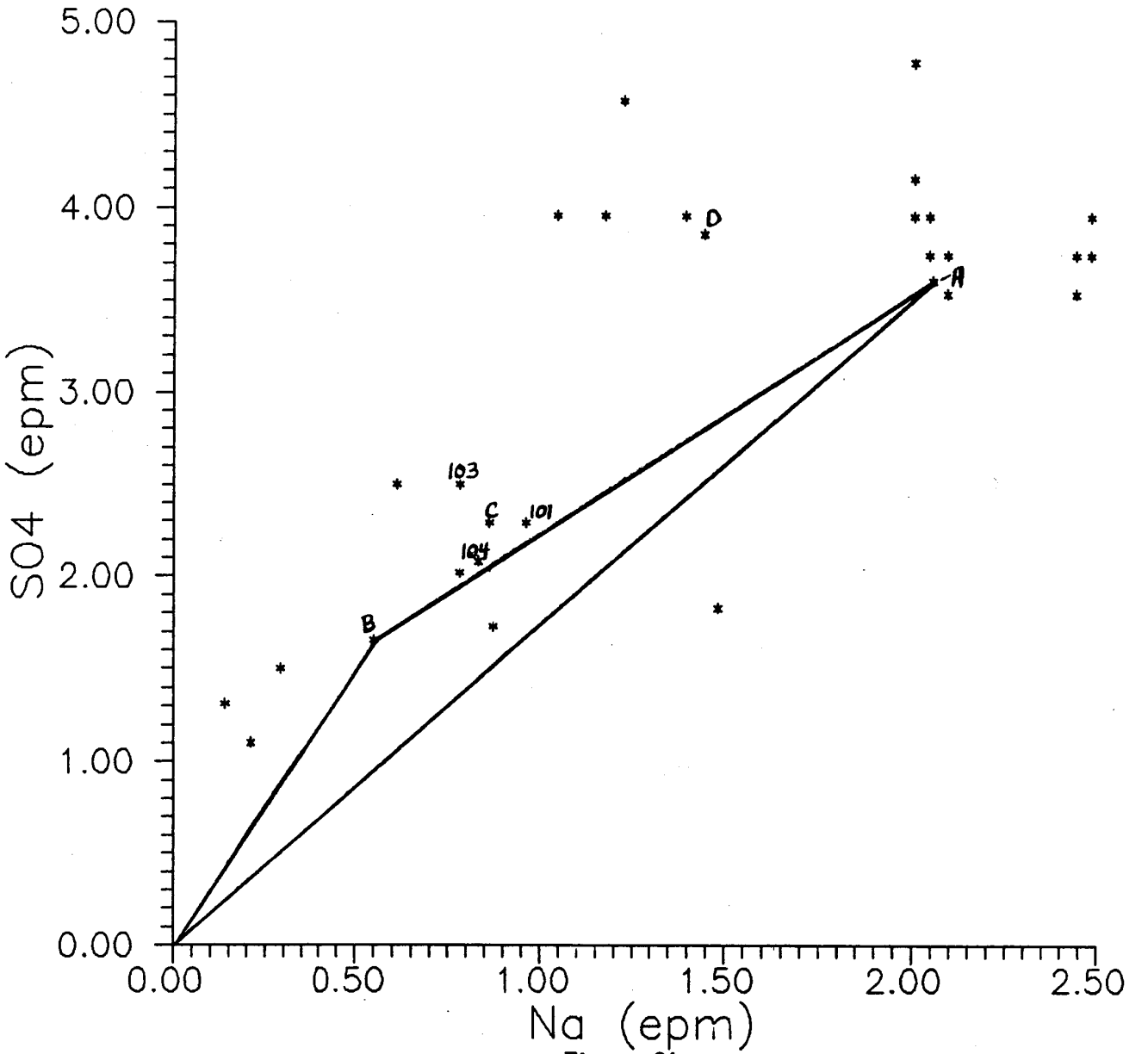
4.00
3.00
2.00
1.00
0.00
SO4 (epm)
0.00
1.00
2.00
3.00
4.00
5.00
Mg (epm)
A
B
C
D
101
103
104

Figure 30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3.00
2.00
1.00
0.00
SO4 (epm)
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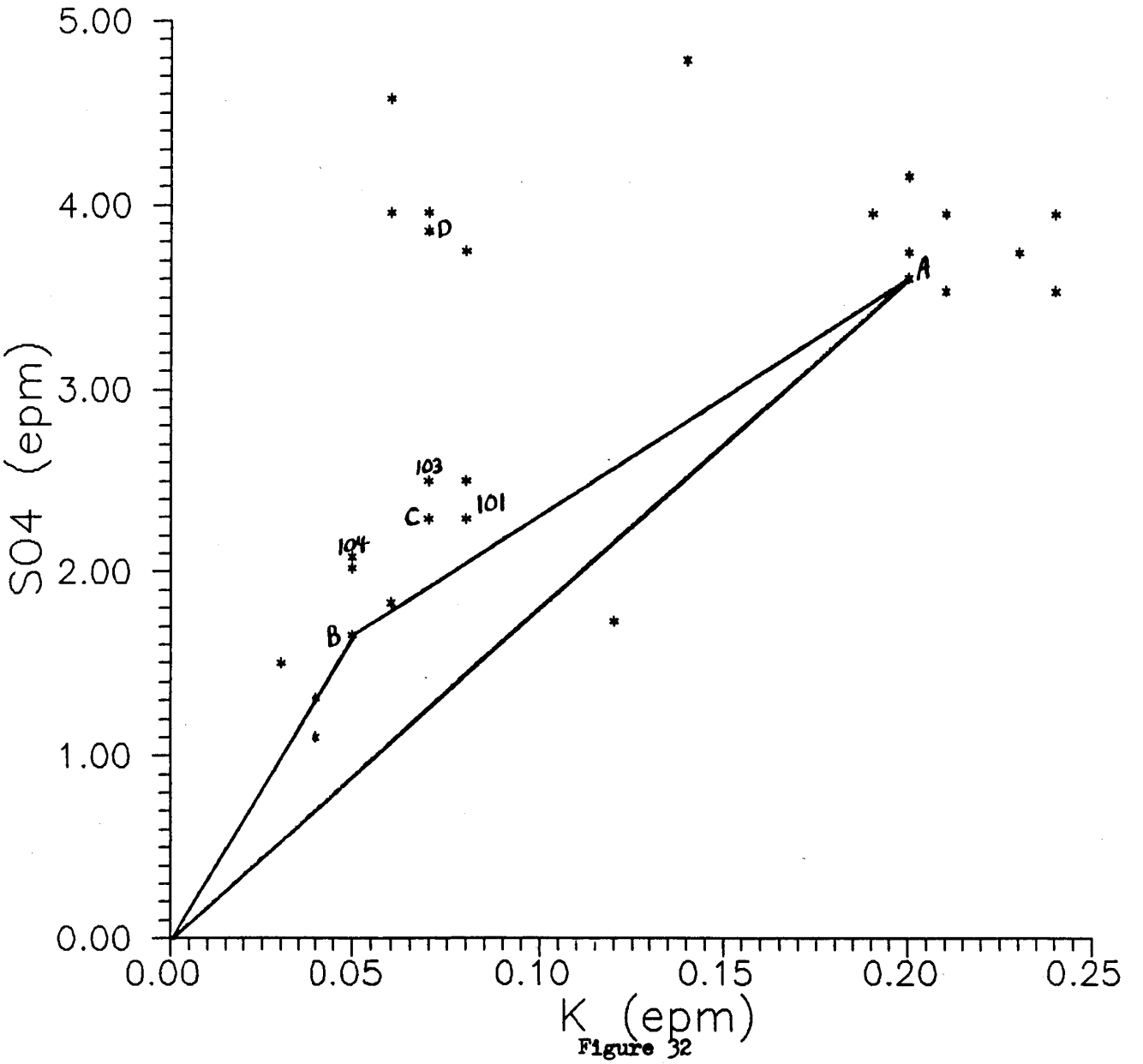
0.50
1.00
1.50
2.00
2.50
Na (epm)
A
B
C
D
101
103
104

Figure 31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2.00
1.00
0.00
SO4 (epm)
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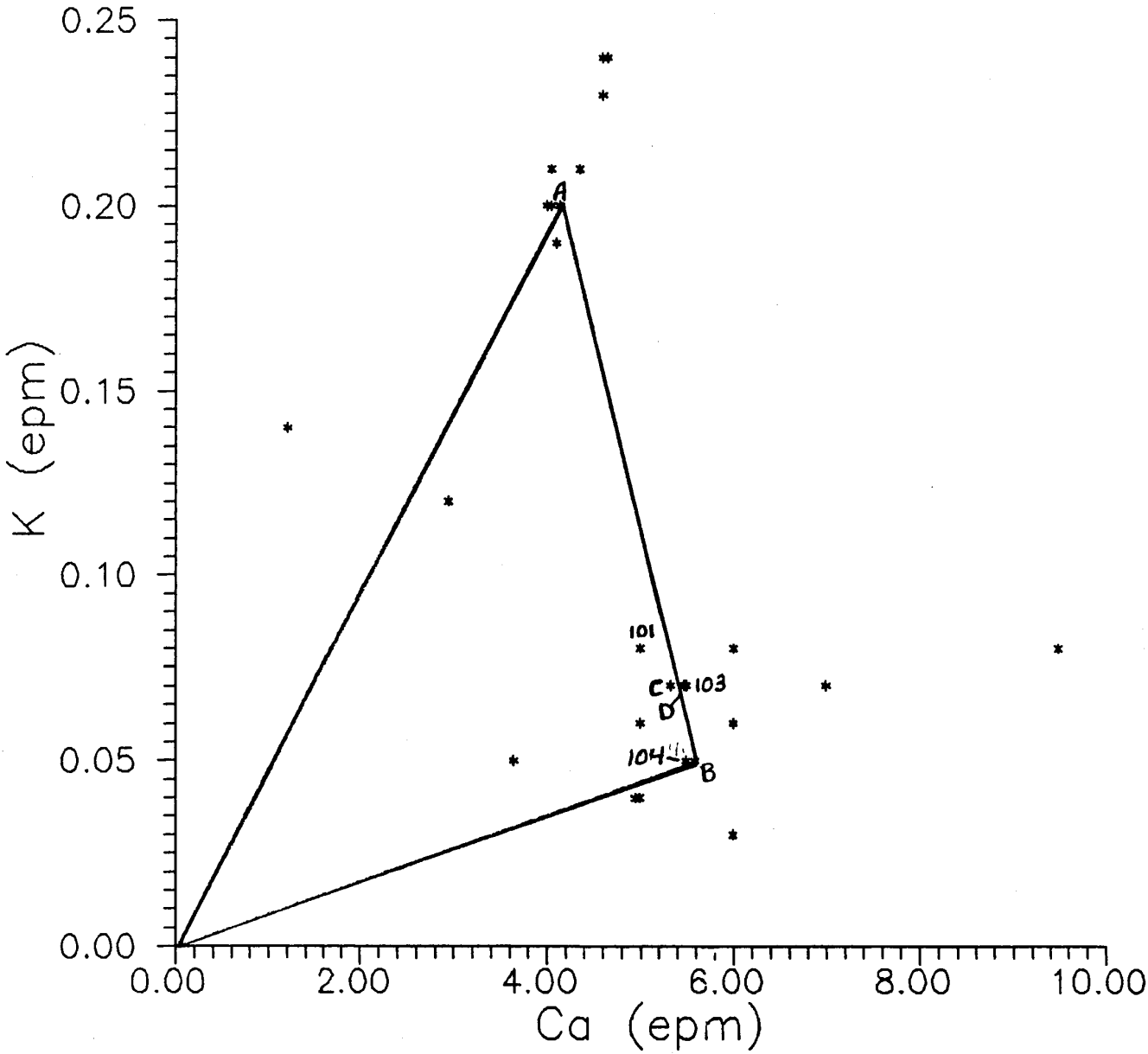
0.15
0.20
0.25
K (epm)
A
B
C
D
101
103
104

Figure 32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0.15
0.10
0.05
0.00
K (epm)
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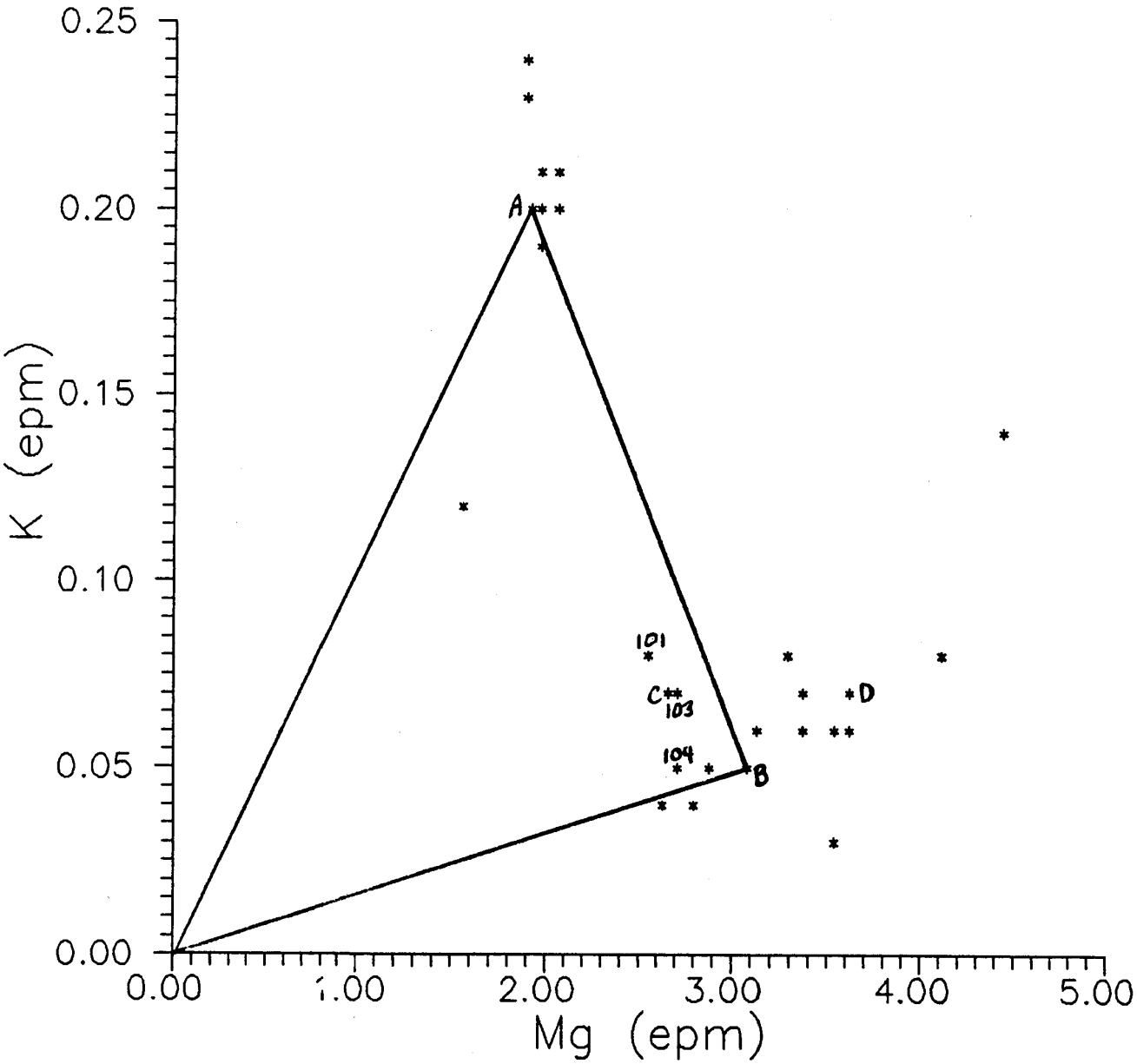
6.00
8.00
10.00
Ca (epm)
A
B
C
D
101
103
104

Figure 33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0.15
0.10
0.05
0.00
K (epm)
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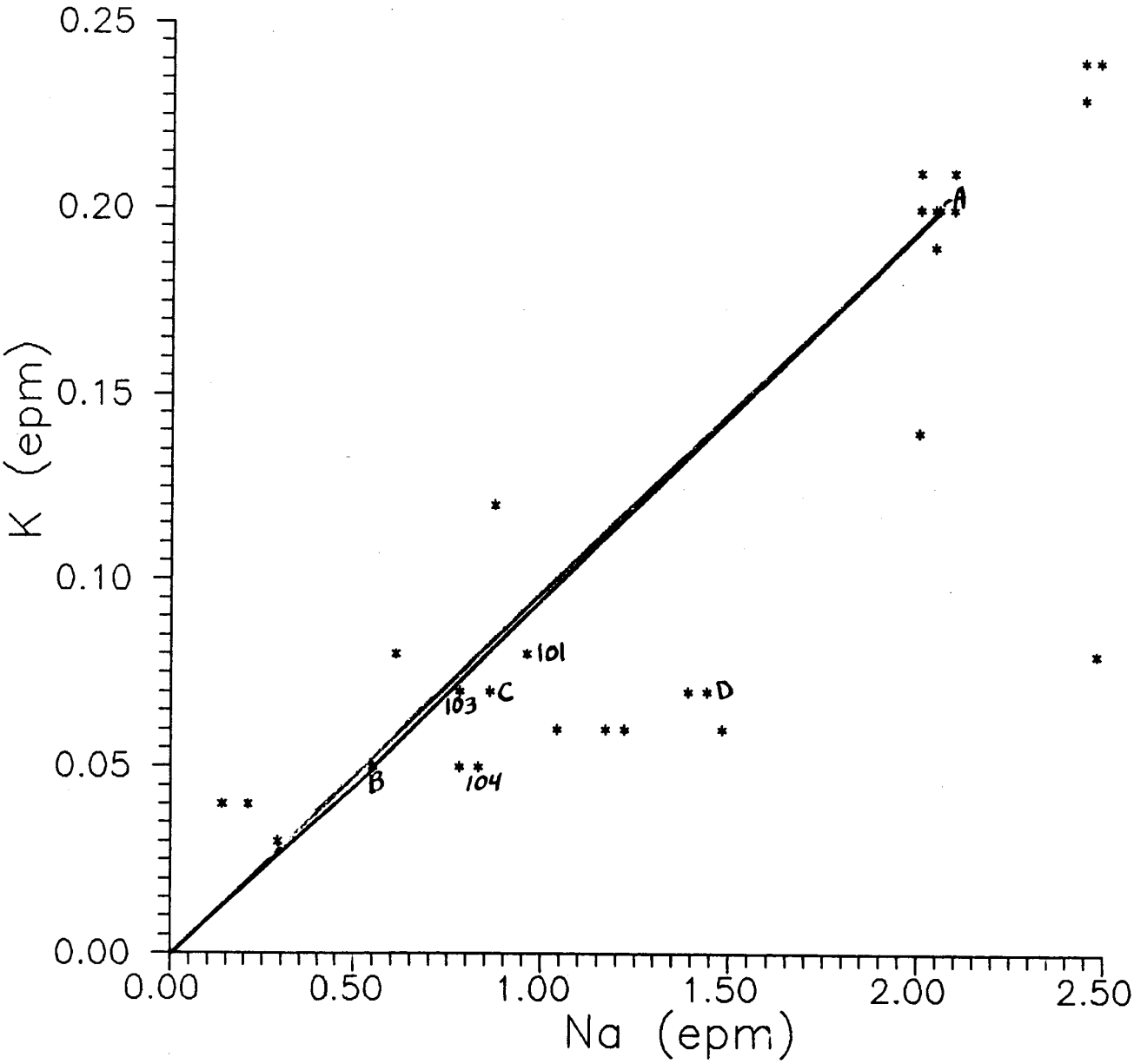
1.00
2.00
3.00
4.00
5.00
Mg (epm)
A
B
C
D
101
103
104

Figure 34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0.20
0.15
0.10
0.05
0.00
K (epm)
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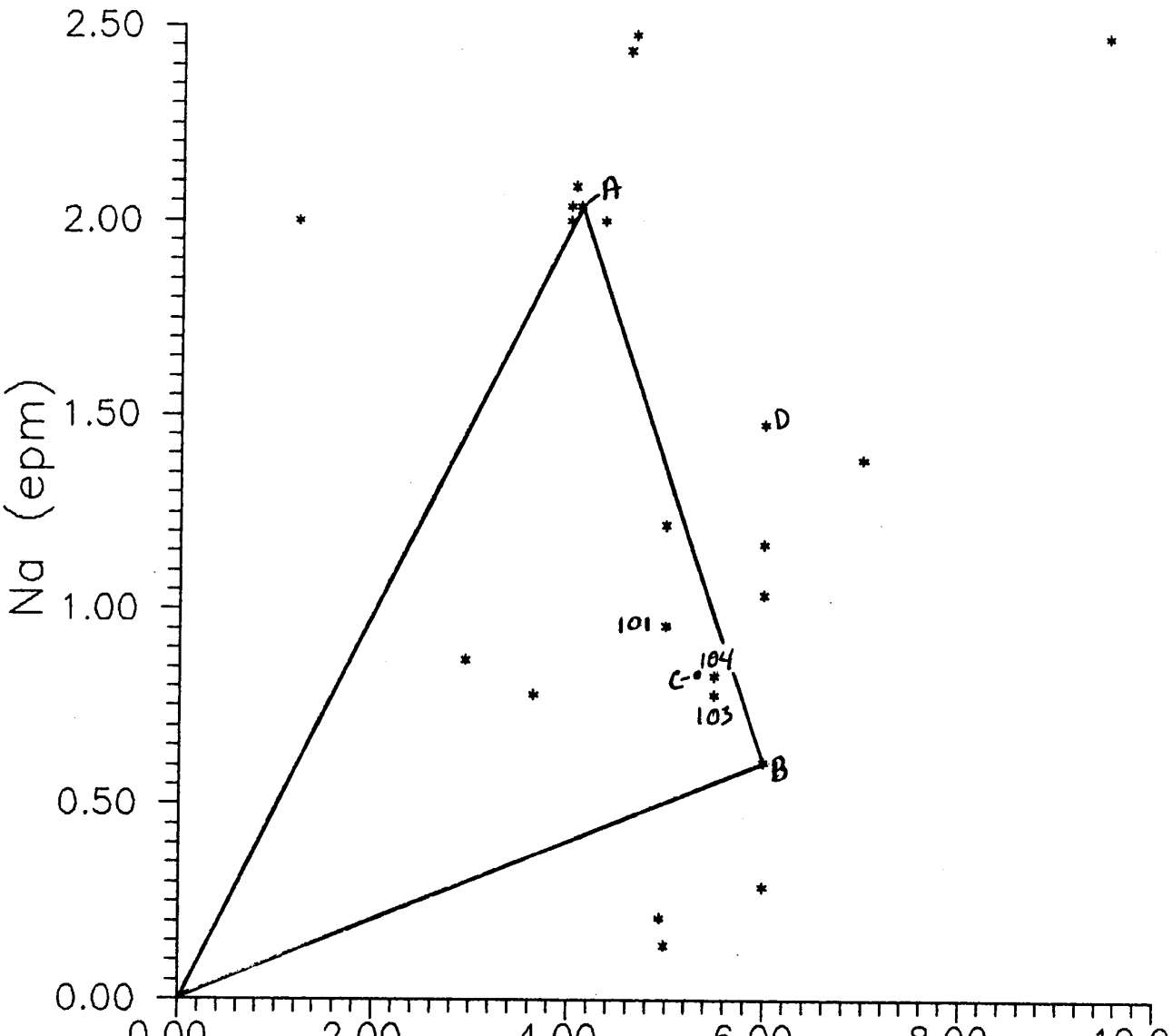
0.50
1.00
1.50
2.00
2.50
Na (epm)
A
B
C
D
101
103
104

Figure 35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Na (epm)
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Ca (epm)
A
B
C
D
101
103
104

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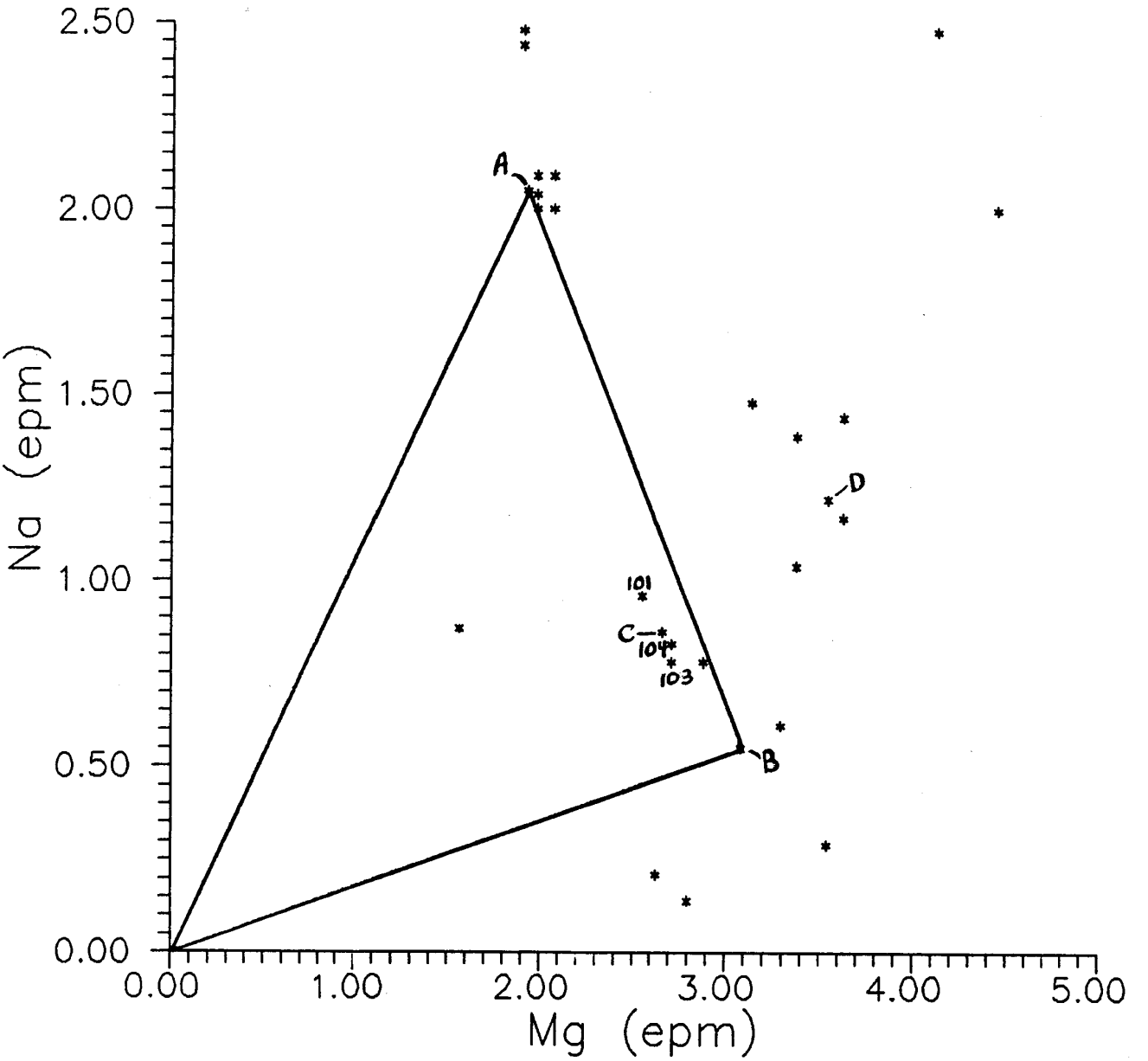
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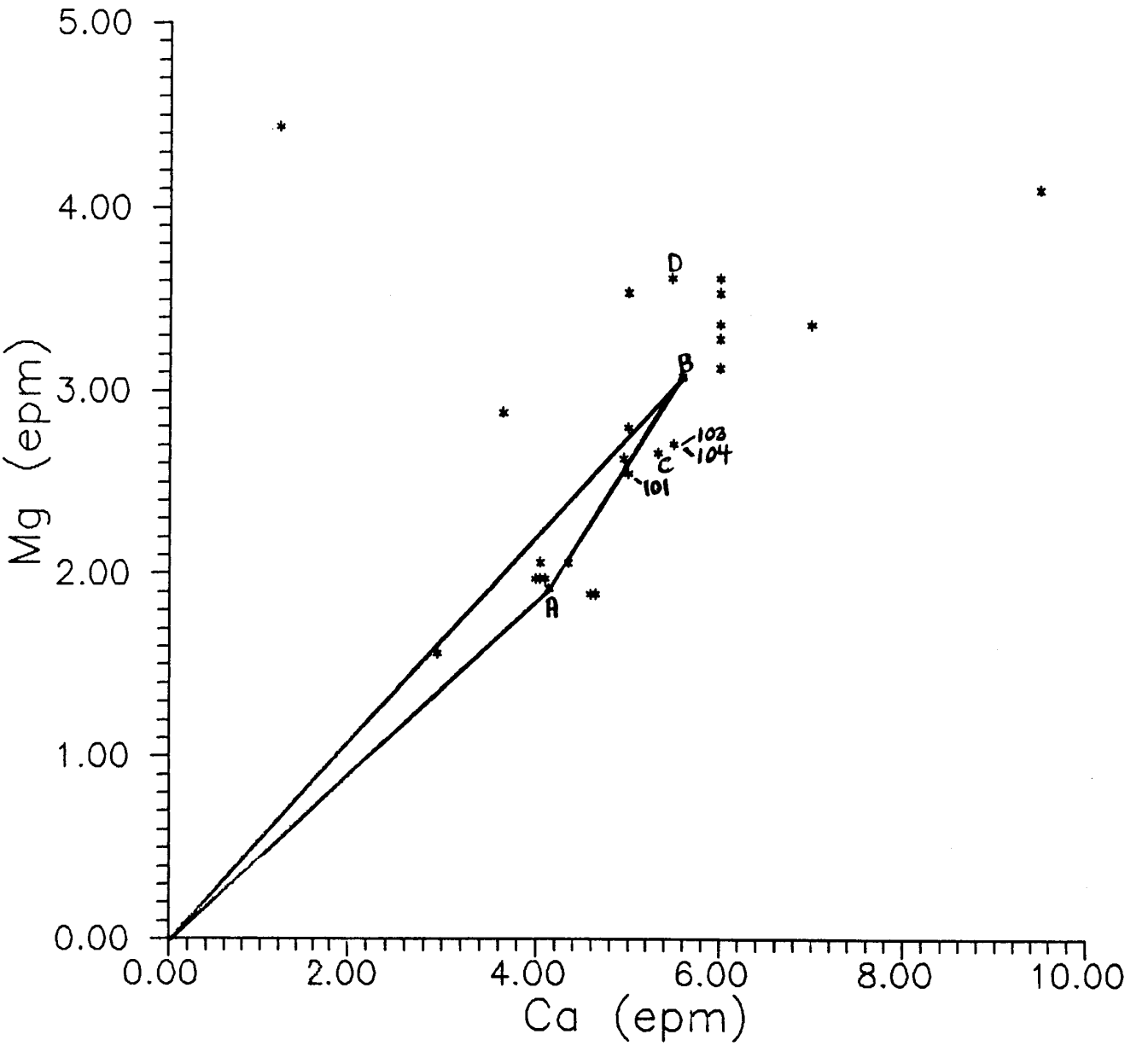
5.00
Mg (epm)
A
B
C
D
101
104
103

Figure 37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1.00
0.00
Mg (epm)
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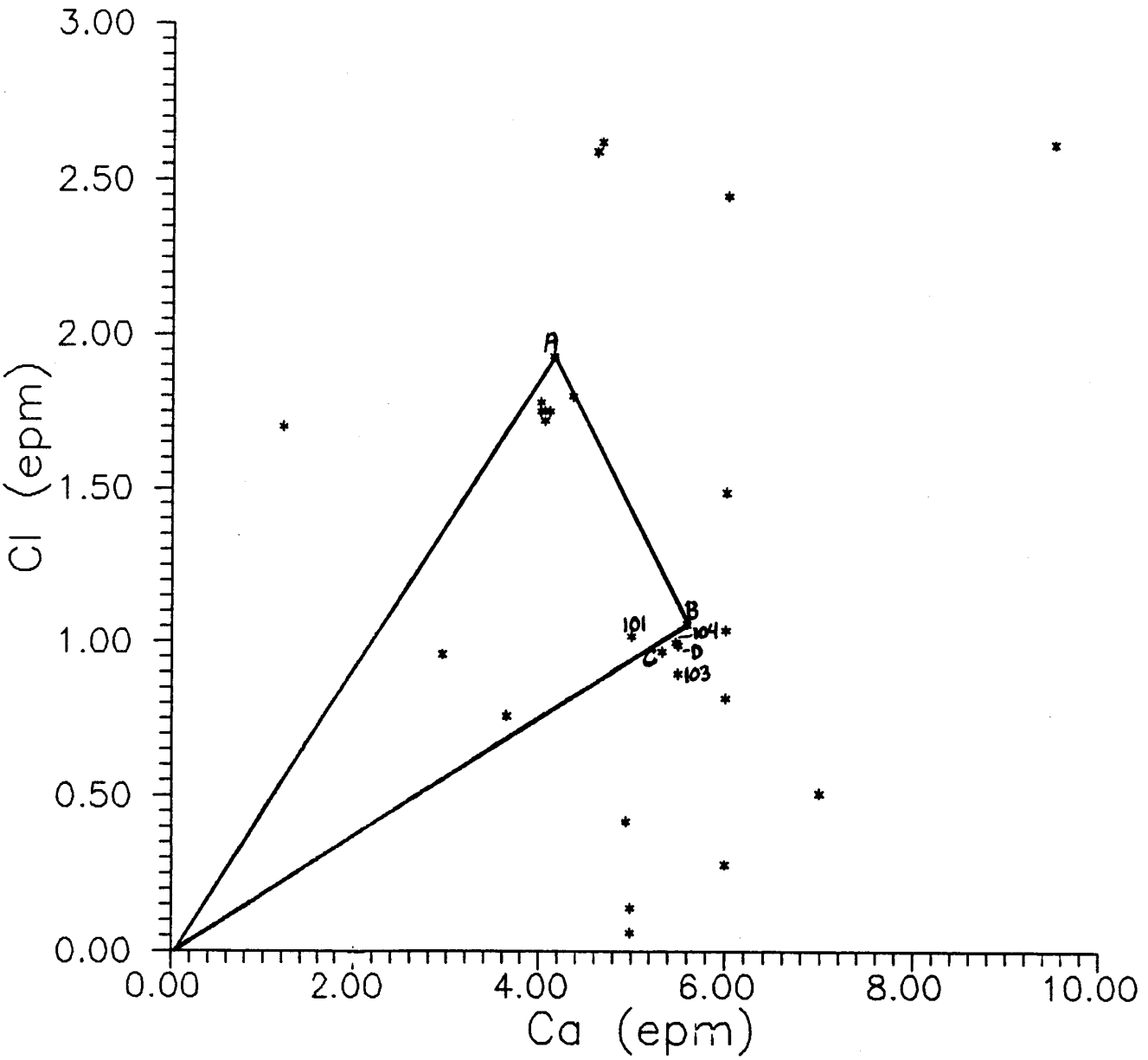
4.00
6.00
8.00
10.00
Ca (epm)
A
B
C
D
101
103
104

Figure 38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2.00
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0.50
0.00
Cl (epm)
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2.00
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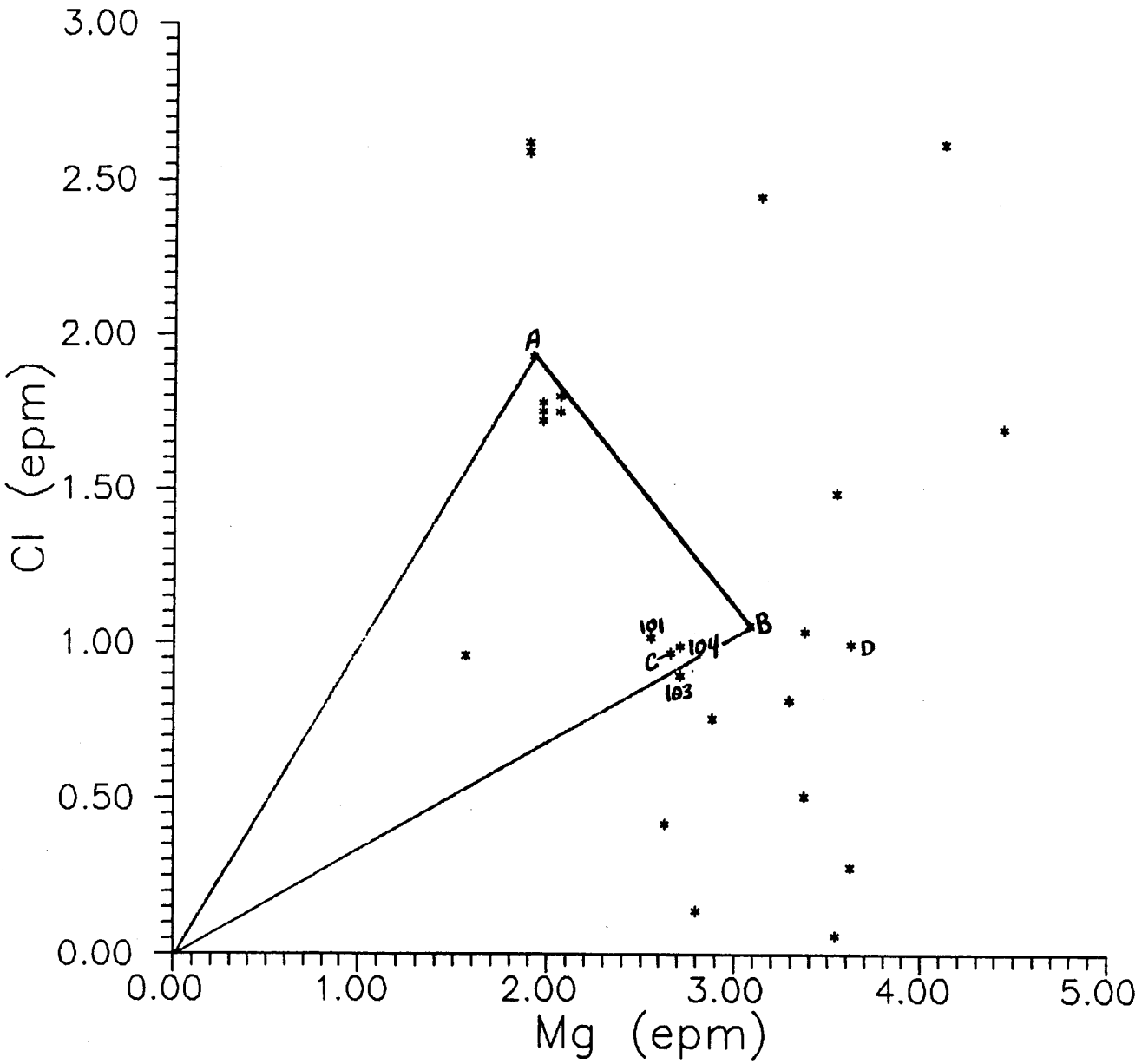
8.00
10.00
Ca (epm)
A
B
C
D
101
104
103

Figure 39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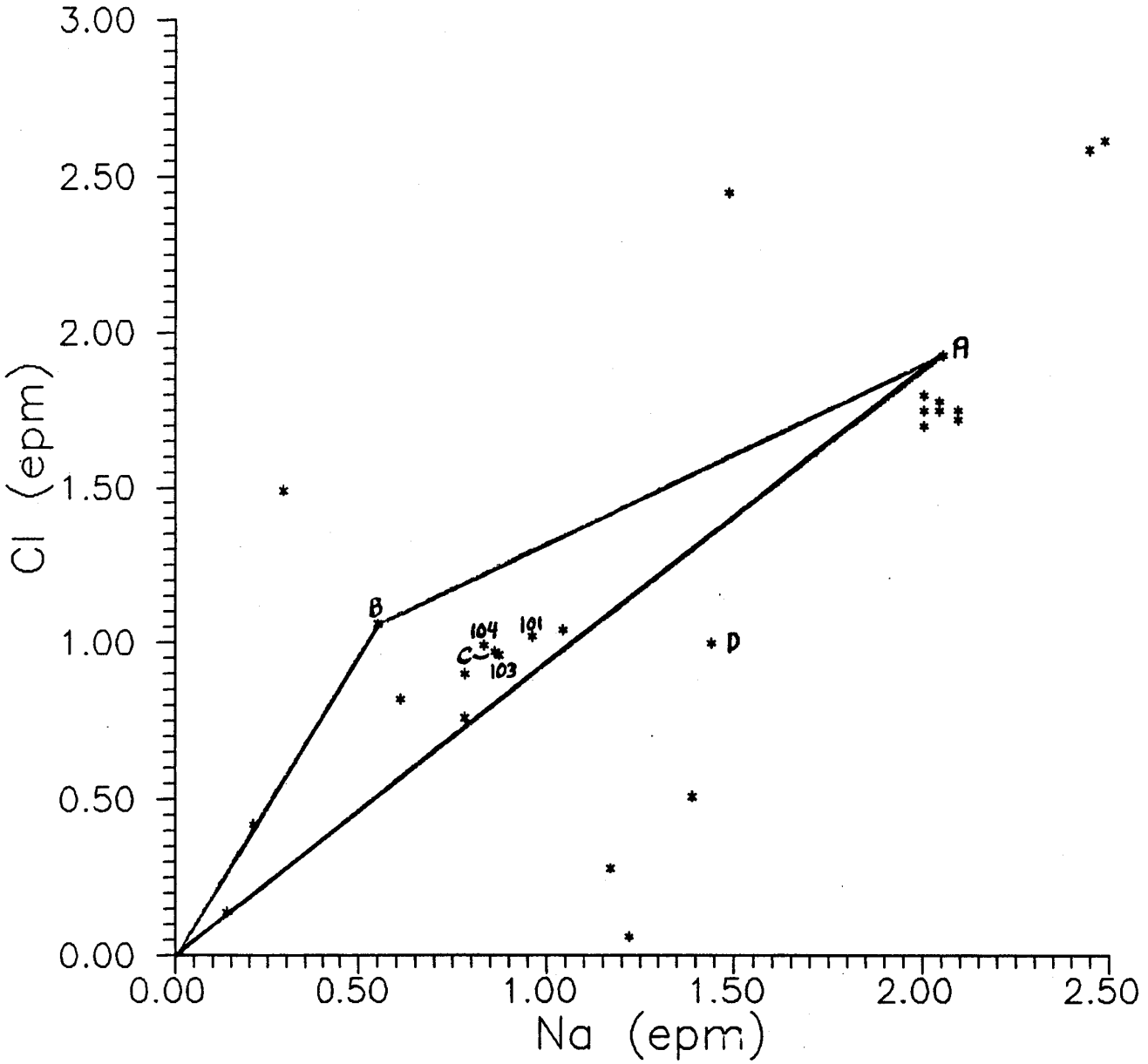
5.00
Mg (epm)
A
B
C
D
101
104
103

Figure 40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2.50
Na (epm)
A
B
C
D
104
101
103

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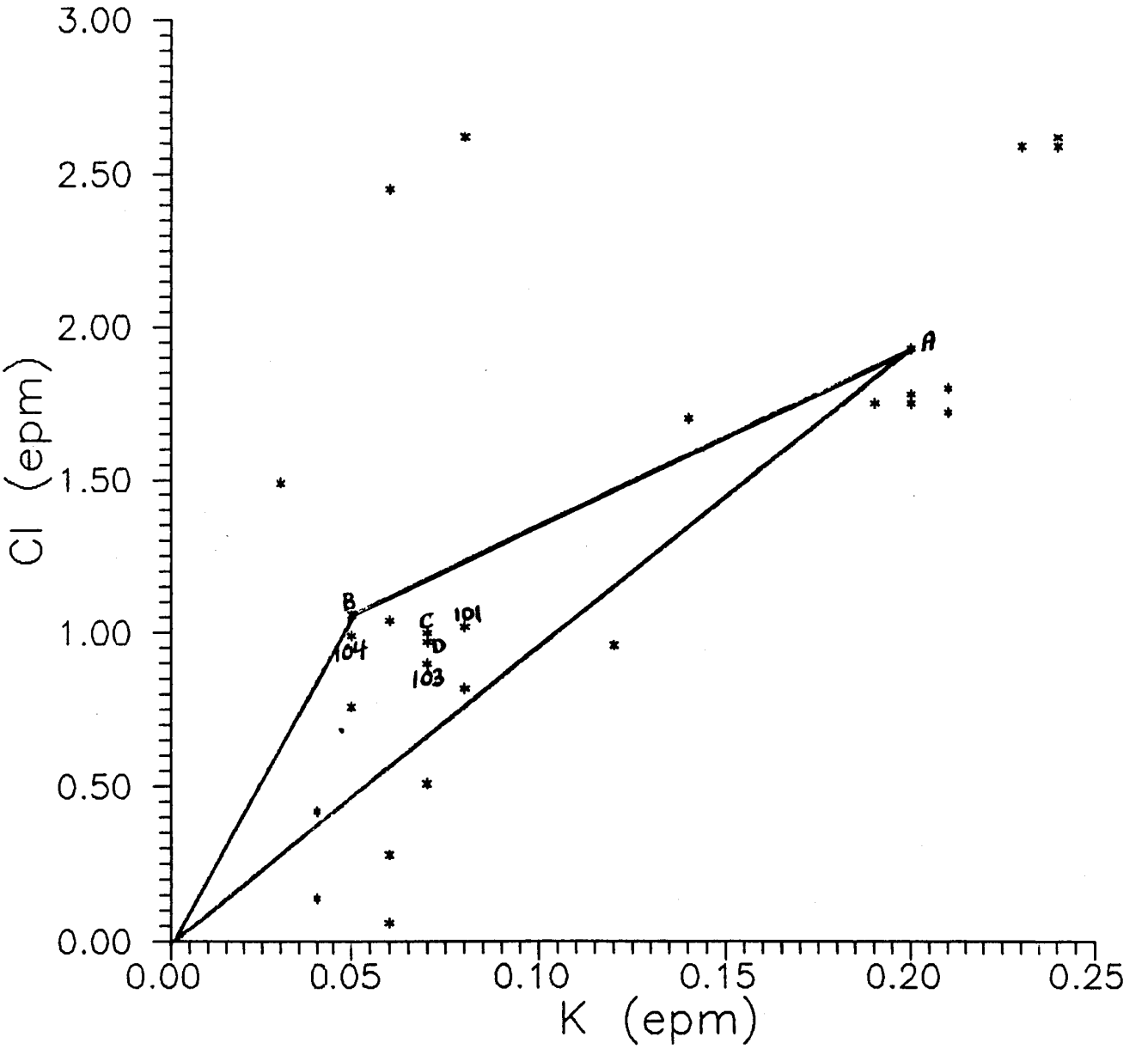
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2.00
1.50
1.00
0.50
0.00
Cl (epm)
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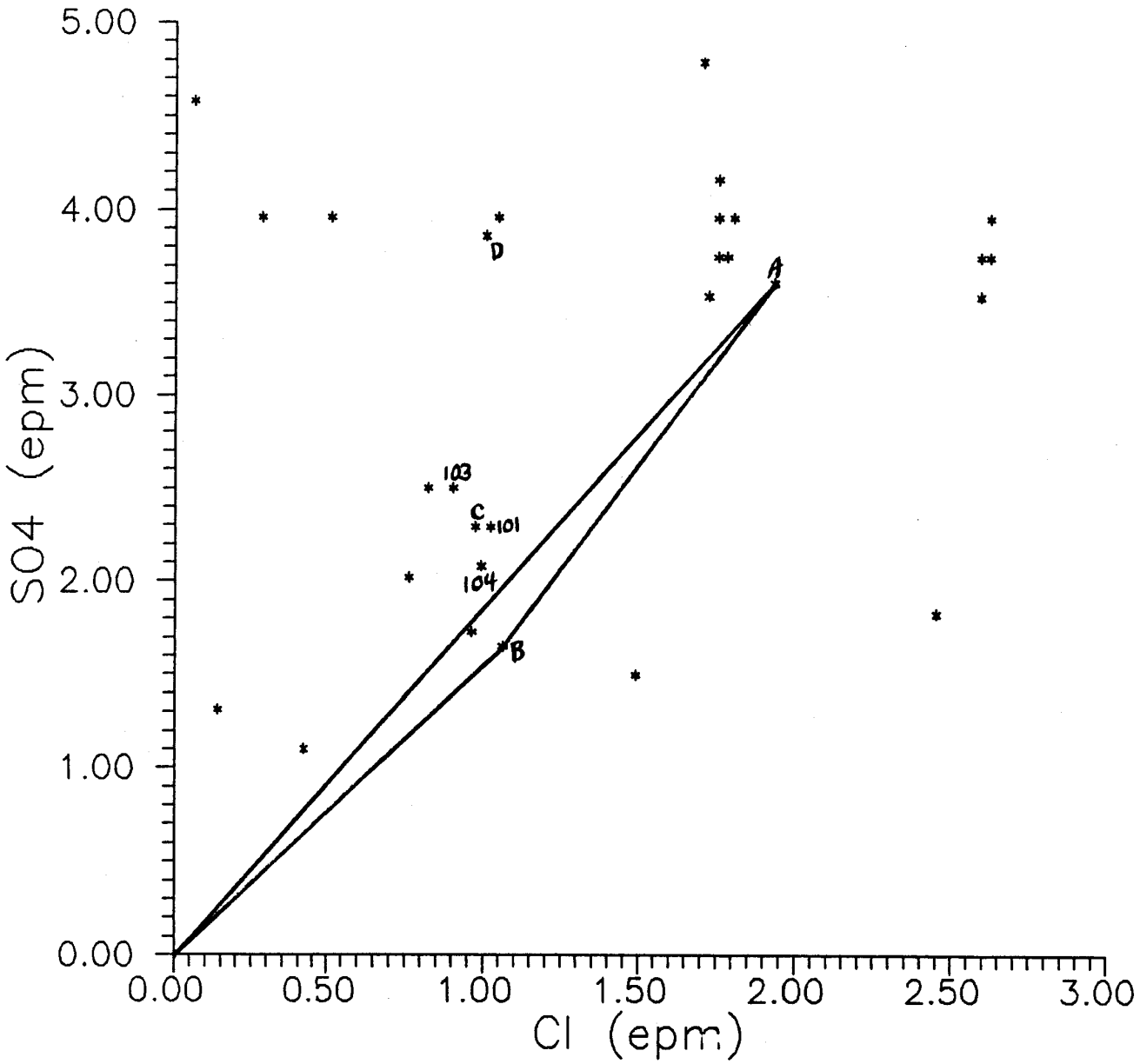
0.15
0.20
0.25
K (epm)
A
B
C
D
101
104
103

Figure 42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3.00
2.00
1.00
0.00
SO4 (epm)
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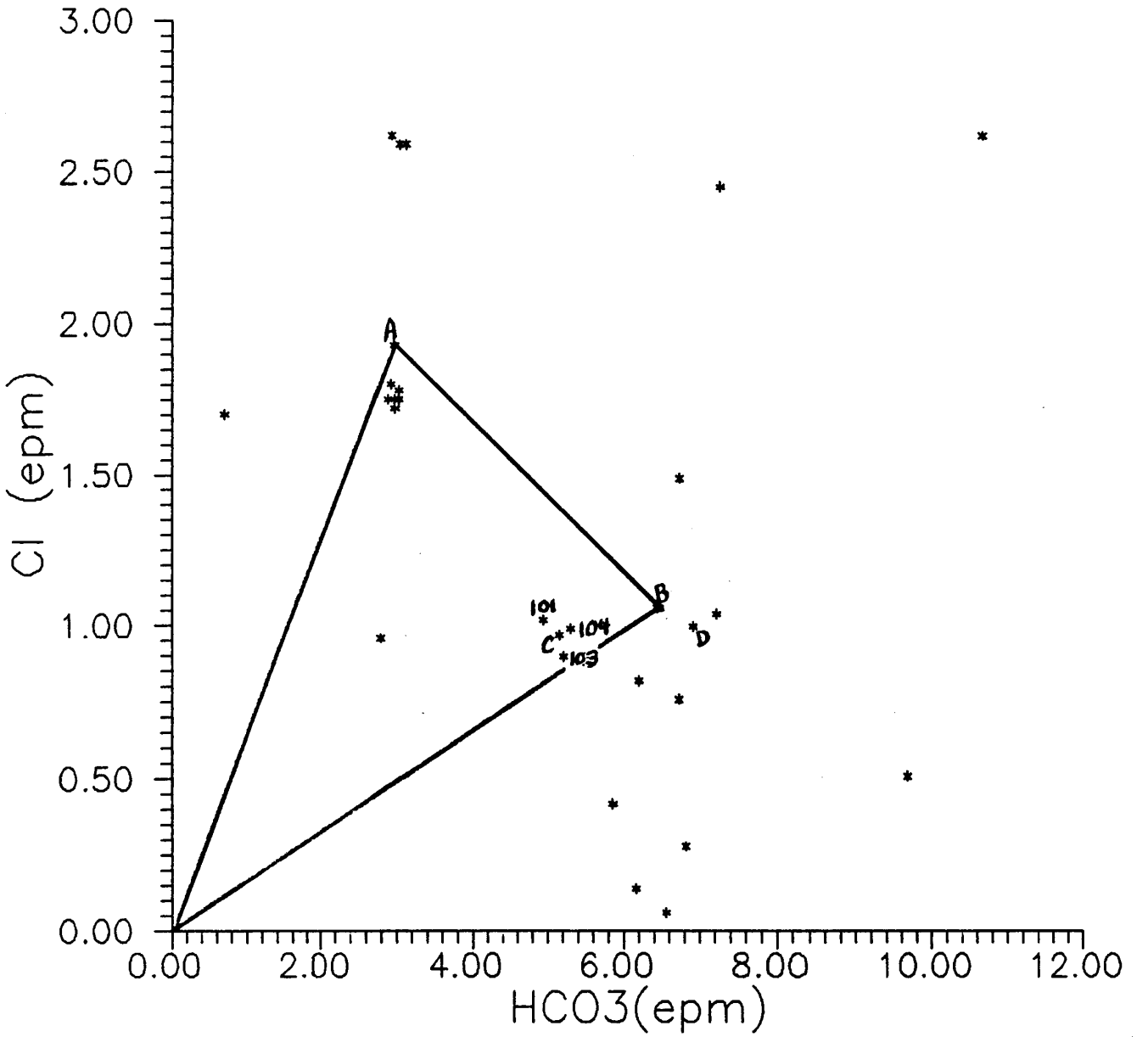
1.00
1.50
2.00
2.50
3.00
Cl (epm)
A
B
C
D
101
103
104

Figure 43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2.50
2.00
1.50
1.00
0.50
0.00
Cl (epm)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
HCO3(epm)
A
B
C
D
101
104
103

Figure 44